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Summary of Recent Technical Information Concerning Thermal Discharges into Lake Michigan

Argonne National Laboratory

prepared for

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Argonne National Laboratory

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Region V Enforcement Division
CONTRACT REPORT 72-1

Summary of Recent Technical Information Concerning Thermal Discharges into Lake Michigan

by

Center for Environmental Studies
&
Environmental Statement Project

Argonne National Laboratory
9700 South Cass Avenue
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Most of these discharges are from electric power plants

27 Abstract

This report is a review of new technical information, relevant to the environmental effects of thermal discharges into Lake Michigan, which is not reflected in the existing record of the Lake Michigan Enforcement Conference. The report discusses separately the physical and biological aspects of thermal discharges. It includes descriptions of preoperational field studies, thermal-bar measurements, field measurements of the physical and biological characteristics of thermal discharges, mathematical modeling techniques, laboratory tests on biological effects of heated water, intake and outfall designs, power plant operational data, analyses of environmental effects and cost estimates of closed-cycle cooling systems, and chemical discharges from both fossil and nuclear power plants.

The report was prepared on an intermediate technical level suitable for the layman as well as the scientist. The authors specifically refrained from drawing conclusions from the material. The conclusions cited were abstracted from the original documents. Where conclusions from similar studies were significantly different, these differences were identified without discussion.

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PREFACE

This report, funded by the U.S. Environmental Protection Agency, Region V, through an interagency agreement with the Atomic Energy Commission, is a review of new technical information, relevant to the environmental effects of thermal discharges into Lake Michigan, which is not reflected in the existing record of the Lake Michigan Enforcement Conference.

Between September 28 and October 2, 1970, the Lake Michigan Enforcement Conference held a workshop in Chicago, Illinois, to consider proposals for regulating waste heat discharges to Lake Michigan. At this workshop, testimony was presented by staff of the U.S. Department of Interior, the power industry, citizens, and various State and Federal agencies. A five-volume record of the proceedings was published.[94] Subsequent meetings of the enforcement conference were held on March 23-25, 1971. A three-volume record of these proceedings was also published.[93]

Though the records of the proceedings of the Lake Michigan Enforcement Conference contain a substantial amount of technical data relative to the environmental effects of the use of Lake Michigan water for cooling, subsequent studies have produced technical results not previously presented to the Conference. This document, therefore, is to provide a summary of these subsequent studies. The intent is that it be used at the forthcoming Lake Michigan Enforcement Conference, to be reconvened on September 19, 1972, as an aid in the discussions and deliberations related to thermal discharges.

The primary sources of information for this report included testimony from local, state, and federal pollution-control agencies; reports from the Great Lakes Fisheries Laboratory of the U.S. Bureau of Sport Fisheries and Wildlife; reports from universities performing research on Lake Michigan; permits issued by the U.S. Army Corps of Engineers; technical and environmental reports prepared by or for power companies discharging into Lake Michigan; and environmental impact statements prepared by the Atomic Energy Commission. Results from studies conducted on bodies of water other than Lake Michigan and reports from the open literature were cited if they were judged to be particularly relevant and as time permitted.

The report is structured to discuss separately the physical and biological aspects of thermal discharges. The section on Ambient Lake Conditions describes preoperational field studies, thermal-bar measurements, and general lakewide phenomena that are pertinent to power-plant siting considerations. The ambient lake conditions are the reference points from which all environmental effects must be measured. The section on Studies Related to Thermal Plumes describes field measurements of the physical and biological characteristics of thermal discharges, summarizes

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mathematical modeling techniques, and describes some laboratory tests on the biological effects of heated water. The section on Intake and Discharge Effects summarizes operational data from most of the power plants on Lake Michigan, describes the intake and outfall designs of the five major nuclear facilities sited on the lake, and discusses biological effects observed at various power plants.

The feasibility of using closed-cycle cooling systems instead of once-through cooling was discussed at previous Enforcement Conference hearings. There is little disagreement that the general concept of closed-cycle cooling is feasible, with the possible exception of certain site-specific problems. The section on Alternative Cooling Methods describes several analyses of closed-cycle cooling systems as reported in some of the Environmental Impact Statements and summarizes available data on estimated costs of original installations and backfitting. Chemical discharges from both fossil-fired and nuclear power plants are tabulated in the section on Chemical Inputs. This section also describes chemicals used in condensers, process-water systems, cooling towers, and ponds and reports on recent experiments to study the biological effects of various concentrations of these chemicals.

The intent was to prepare this report on an intermediate technical level suitable for the layman as well as the scientist. The review of any individual reference is necessarily brief and is primarily to call attention to the source if information in greater depth is required. We have specifically refrained from drawing conclusions from the material reported here to minimize the influence of our particular beliefs.

The conclusions cited in this review are abstracted from the original documents. Where the conclusions from similar studies are significantly different, these differences are identified without discussion.

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I. INTRODUCTION

Lake Michigan is a precious natural resource with many potential beneficial uses for man. He uses it for drinking water, recreation, transportation, food production, waste disposal, and cooling, to name a few. Any of man's uses of the lake will have an effect, though some uses have significantly greater effects than others.

We are beginning to observe the results of some of our uses of this body of water, and many have expressed concern about the trends they have seen. The general public has recently become aware of a number of the potential problems, and their interest in preserving the lake for its "best and highest use (uses)" is growing rapidly. This is aptly demonstrated by the organizing and convening of several sessions of the Lake Michigan Enforcement Conference over the past few years and the attendant public interest in them.

The use of Lake Michigan for cooling is receiving a large portion of the public's attention these days. The magnitude of water being used and the projected requirement for the future is difficult to comprehend, and the public is rightfully questioning what the effects will be. Unfortunately the scientific and technical information needed now to make rational decisions is not available. Only recently have the resources, in terms of manpower and dollars, been made available to acquire this information. The results of this developing effort are summarized here for use in the considerations related to thermal-discharge standards.

The lake areas influenced by the thermal discharges are only of intesest in relation to their biological effects. Temperature controls the rates of most biological processes (metabolic rates, disease, predation, etc.) and increases in temperature from the thermal plumes may cause direct and indirect effects on biological systems. Potential sources of biological damage associated with once-through cooling are summarized in the Final Environmental Statement for the Palisades Nuclear Generating Plant.[119] They are:

(1) Temperature increases of the cooling water, causing both direct effects and indirect effects on metabolism, growth, disease, predation, etc.

(2) Mechanical and pressure changes that damage small organisms passing through pumps and condenser tubing.

(3) Impingement on intake screens of larger organisms, principally fish, drawn into the cooling-water intake.

(4) Chemicals used as biocides (usually chlorine) to remove slimes from the condenser tubing, and perhaps other chemicals released to the cooling water from a variety of plant operations, all of which may be toxic to aquatic life.

(5) Induced circulation of a water body, both in the local area of the discharge (which may influence migrations) and in the wider range of the water body (changing normal seasonal patterns).

(6) Radiation derived largely from radioactive nuclides taken up by terrestrial and aquatic organisms, which could potentially induce radiation damage if concentrations of the nuclides were sufficiently high.

A seventh could be their combined effects.

Reference 119 presents a rather comprehensive discussion of these potential sources of biological damage and is recommended as an excellent summary.

The general subject of effects of temperature on aquatic organisms has been reported in several scientific reviews that became available in 1971. Since this report is limited specifically to Lake Michigan, and since it is impractical to review a review, our guide to this wealth of new information will consist of a single reference to the publication by Coutant, "Thermal Effects (Biological): A Review of the Literature of 1971 on Wastewater and Water Pollution Control."[35] The review describes some 390 references, practically all of which are dated 1971 or 1970.

II. AMBIENT LAKE CONDITIONS

Adequate knowledge of ambient lake conditions is required for at least the following three reasons:

1. Standards are being developed to guide our actions in the design and siting of power-generating stations. Knowledge of ambient conditions is necessary to evaluate the validity of the standards as applied to different areas; i.e., do the ambient conditions violate the standards? Knowledge of ambient conditions is also necessary in the enforcement of the standards. The baseline from which the standards will be applied must be clearly defined so that subsequent actions may be quantified for evaluation.

2. Adequate background knowledge is required for use in evaluation of potential sites and for reliable design calculations.

3. Background information in specific areas is necessary for the observation of potential changes or damage that may incur as the result of man's use of the lake.

There are data in the literature, and being developed, that describe the overall lake characteristics such as major circulation patterns, temperature regimes, biological characteristics, and aquatic inhabitants. In addressing the problem of thermal discharges, however, we are concerned with the near-shore regions and their specific characteristics, and the ways in which they differ from the lake norm and from other regions with which they might be compared.

A. Physical Characteristics

This section describes ambient data, relevant to Lake Michigan, published since 1970. The summaries are organized with respect to geographical areas associated with existing power-plant sites.

1. Lake Temperatures

Ambient lake temperatures have been measured periodically in the Zion-Waukegan area since 1969. Reference 12 presents data in graphical form that shows the near-shore temperature distribution as a function of depth. Some of the most pertinent features of the data include the spatial variability of the temperatures and the documentation of the thermocline. For instance, an ambient temperature profile obtained in August 1970, east of the Waukegan Harbor, shows[12] the temperature decreasing from 64.4 to 50°F between the depths of 13 and 16 ft. The ambient surface temperatures near shore were observed to vary from 62.6°F at Zion to 65.5°F at Waukegan Harbor, a distance of 4 miles. The ambient surface temperature also increased in the offshore direction to over 70°F at a distance of 6 miles. This was apparently an upwelling condition.

The Bio-Test Laboratories reported[66] that ambient temperature differences of as much as 3.6°F in 980 ft made it difficult to clearly define the perimeter of the thermal plume at Waukegan.

A graphical representation[67] of ambient lake temperatures on February 16, 1971, 2000 ft south of the Waukegan Generating Station, shows that, except for a very small region at a depth of about 12 ft, the temperature is essentially uniform at 32 to 32.5°F at all depths to an offshore distance of 16,000 ft. On March 10, 1971, all top-to-bottom temperatures were determined to be 32.0°F.[68] Ambient temperatures measured on June 2, 1971, showed[69] weak stratification with inshore heating. Inshore surface temperatures were 52-53°F; 2 miles offshore the surface temperature was 47°F, and the bottom temperature at a depth of 45 ft was 41°F.

Water-temperature measurements[69] at Zion, during April-December 1971, ranged from 37.8 to 72.5°F, the lowest in April and the highest in August. The thermal behavior of the Zion-Waukegan area was summarized as follows:[69]

"Generally, inshore water temperatures were somewhat higher than offshore during the spring and fall, while the reverse was true in summer months. A thermal bar was observed in April and December near the offshore (sampling) stations (approximately two miles from shore).

"The spring overturn continued until early June, when the thermocline appeared. .... Thermal stratification began in June at the Waukegan station. However, the thermocline was not observed at the Zion area until early July. The height of summer stratification was found in August and disappeared during the mid-September sampling period as fall mixing began in the area."[69]

Average monthly water temperatures for the Waukegan, Chicago and Milwaukee water intakes are compared in Fig. 2.5 of Ref. 26.

Lake temperatures at several stations near the Point Beach Nuclear Plant were measured, starting in April 1969. There was a general slow warming trend from April through July, reaching the high 60's, with only moderate temperature fluctuations. However, in August and September, upwelling conditions produced temperature fluctuations of greater than 20°F in several days. The maximum and minimum temperatures during August were 71 and 46°F, respectively. From August 4 to August 9, the temperature at the intake dropped from 68 to 48°F.[126]

Temperature data obtained from April to December 1970 essentially confirmed the 1969 data.[127] Similar data obtained in 1971 showed a temperature high of only 63°F during mid-September. This is about 8°F lower than the highest temperatures observed during August in the 1969 and 1970 studies. The large ambient-temperature fluctuations of up to 20°F observed in 1969 and 1970 were not observed during 1971.[128]

During studies of a sinking plume,[59] ambient lake temperatures, at depths of 16-36 feet, were observed at Point Beach and a station 2 miles north during March and April 1971. During March, the bottom temperature increased slowly from 32 to 35°F, with relatively little fluctuation. From April 3 to April 17, it increased from 35 to 40°F with daily variations of up to 3.6°F over periods of 3-6 hr. Ambient-lake-temperature measurements at the Kewaunee site[131-133] were basically in agreement with the Point Beach data for the same period. The Kewaunee site is approximately 4.5 miles north of the Point Beach site.

On the eastern side of Lake Michigan, an ambient-lake-temperature sensing and recording system was actuated at the Cook Plant Site in May 1970. Temperatures were measured at various depths at both 300 and 2500 ft offshore. Results of the measurements obtained through February 1971 are tabulated in Ref. 5. The data consist of daily maximum and minimum water temperatures obtained at the Cook Plant site and at the Benton Harbor and St. Joseph water-plant intakes.

Previously unreported data giving the average temperatures of intake water during 1969 at the J. H. Campbell Plant at Port Sheldon, Michigan, is presented in Ref. 119. The J. H. Campbell Plant is located about 40 miles north of the Palisades Plant. These data showed a maximum temperature of 77°F in August and variations of up to 13°F within one day.

Average monthly water temperatures near the Bailly Generating Station for October 1970 through September 1971 are tabulated in Ref. 120. These data were obtained at the Burns Harbor Plant of the Bethlehem Steel Company, immediately west of the Bailly site.

2. Inshore Currents

Inshore currents are primarily wind driven and are therefore quite variable, both spatially and temporally. Relatively little inshore-current data are available in the literature.

On the west side of the lake, near the Point Beach site, current velocity measurements were made at 20-min intervals during August to October 1965, at a location 2 miles off the coast of Sheboygan. The data, reported[129] in terms of persistence, are shown in Table 1.

Drogues were tracked on three separate days in 1971, near the Kewaunee site, to observe the near-shore currents. Under calm conditions,

Table 1

Current Velocity Persistence
Near Sheboygan, Wisconsin, 1965[129]

Current (ft/sec)	Persistence (% of time)
0-0.5	68
0.6 - 0.7	10
0.8 - 0.9	12
1.0 or higher	10

preceded by a 5-10-mph north wind, the drogues drifted south at an undetermined velocity (due to fog). Under the influence of offshore winds, a drogue 500 ft offshore, moved in an offshore direction (east) at 0.2 fps, and a drogue 200 ft offshore moved south at a speed of 0.4 fps. With an onshore wind, the drogues moved shoreward and north at 0.16 fps.[70]

Current measurements taken near the Zion site during 1969 were reported to range from 0.07 to 1.09 fps, with most values within 0.2-0.5 fps.[26]

Measurements of inshore lake currents in the Palisades Park, Michigan, area[61] are summarized in the Palisades Environmental Report (Revised).[29] On the basis of wind records, it was estimated that an alongshore current flows northward about 33% of the time and southward about 23% of the time. Offshore winds occur about 38% of the time, but these are expected to have a minimal effect close to shore and the along-shore currents should tend to persist, once set up, while offshore winds are blowing. Thus, the frequency of along-shore current flow should be somewhat greater than cited above.

The Bailly Environmental Report[91] cites drogue studies (unreferenced) as showing that surface currents (upper 5 ft) are directly wind-driven and respond to wind shifts within 1 hr. At the 5-ft depth, currents were skewed 27° to the right of the prevailing mean wind. Current velocities in the upper layer were measured to 1.6 fps. However, typical velocities were much less.

3. Thermal Bar

The "thermal-bar" mechanism develops when waters reach a temperature associated with the maximum density of water (39.2°F). As the surface waters warm in the spring, or cool in the winter, they eventually achieve a temperature of 39.2°F and, being more dense than the surrounding water, they tend to sink. This downward flowing region of 39.2°F water, called the thermal bar, is visualized as separating the inshore waters from the mid-lake water. The inshore waters are warmer than midlake water in the spring and cooler in the winter. During spring, the inshore side of the thermal bar develops a thermocline separating the rapidly warming surface water from the deeper, cold water. Offshore of the thermal bar, vertical mixing extends from the surface to the bottom due to the absence of a thermocline. The thermal bar often exhibits turbidity and color gradients on the lake surface at the point of offshore and inshore flow convergence.

The thermal bar is not static. Except for occasional shoreward movement, its main movement is from inshore to offshore until it eventually disappears in midlake. The thermal bar lasts for 4-8 weeks in Lake Ontario (and Lake Michigan) and is believed to be controlled by surface (solar) heating and the heat capacity of the lake.[100]

Ambient-temperature measurements have revealed the presence of thermal bars on several occasions in the Zion-Waukegan area. Bio-Test studies[12] of ambient lake temperatures, approximately 3 miles north of the Waukegan Station, recorded the thermal bar on April 23, 1970, approximately 16,600 ft (3.1 miles) offshore. Figure 1 is a graphical representation of the data and shows fairly uniform temperatures on one side of the bar (39.2°F isotherm) and thermal stratification on the other. Ambient temperatures in excess of 48°F were found near shore. On April 30, 1970, no evidence of the bar was found out to a distance 36,000 ft (6.8 miles). The offshore velocity for this particular observation was, therefore, at least 0.53 mile/day.

Water temperatures indicating a weakly defined thermal bar were observed on December 18, 1970.[67] The bar was 29,920 ft offshore. At 4250 ft to the east, or offshore side of the bar, the temperature was 39.6°F from top to bottom; 4260 ft to the west of the bar, the temperature was 38.8°F. Measurements and analysis of water samples collected from top, middle, and bottom depths, at both these locations, indicated no significant differences in pH, chlorides, conductivity and dissolved oxygen.

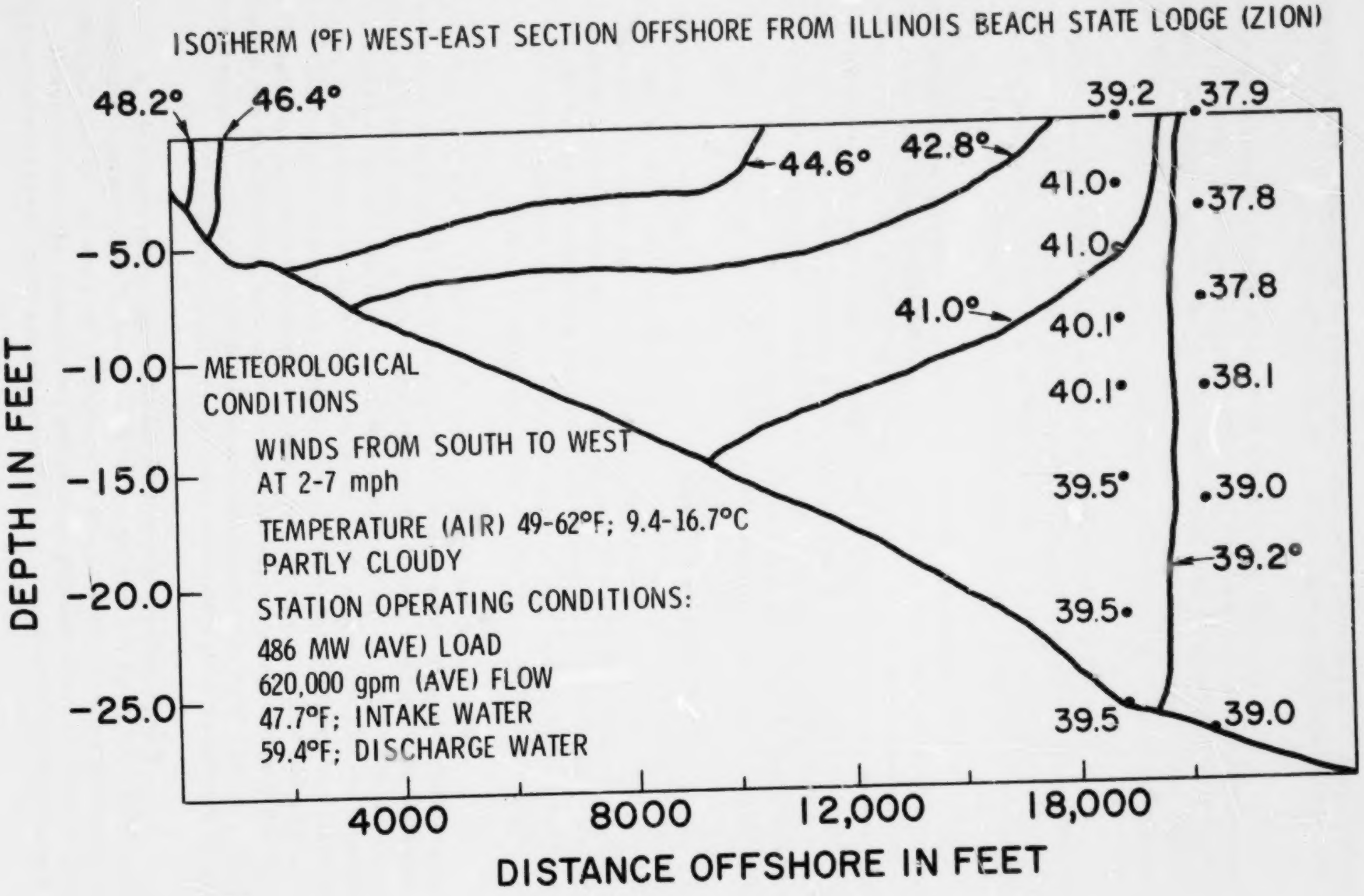
The spring thermal bar was again observed and documented[68] on April 20 and May 3, 1971, in the Zion-Waukegan area. Offshore temperature transects were made from the Zion site, the Waukegan plant, and a point in between. The bar was located 8000, 8000, and 5000 ft offshore, respectively, at these three locations. The bar was well defined with cooler water to the east nearly isothermal from top to bottom, while the inshore water to the west was well stratified, with top to bottom temperatures varying from 45 to 41°F.

A comparison of water-quality samples taken 600 ft from the bar, on both the inshore and offshore sides, showed dissolved oxygen and pH values to be similar. However, there was a tendency toward lower values for chlorides, conductance, and turbidity in samples taken from the offshore side, as compared with samples taken from the inshore waters.

Transects made on May 3, 1971, at the Zion site and at a point between Zion and Waukegan, showed the thermal bar to be 17,000 and 19,000 ft offshore, respectively. The bar was less well defined, with thermal stratification less pronounced on the inshore side. The average velocity of movement offshore during this period was 0.12 mile/day at the Zion site and 0.19 mile/day at the test area south of Zion. No chemical measurements were reported during this observation.

The University of Michigan Willow Run Laboratories reported[110] an aerial survey of the thermal-bar development, between Port Sheldon (J. H. Campbell Plant) and Grand Haven, Michigan, between April 22 and May 7, 1971. The survey used an infrared scanner to map surface-temperature regimes and a scanning spectrometer to measure "apparent"

Fig. 1. Ambient Lake Michigan Water Temperatures - April 23, 1970



water-quality variations, primarily in terms of different reflectance spectra. The report includes a number of pictures of the results.

On April 23, the studies revealed significant shoreline heating but no indication of a thermal bar. The imagery obtained April 30 showed a very distinct thermal bar approximately $1\frac{1}{2}$ to 2 miles offshore. On May 7, the bar had moved about 4 miles offshore.[110] Thus, the average offshore velocity was about 0.3 mile/day during this period.

Any interaction between the Campbell Plant plume on the Grand River plume and the thermal bar was not clearly evident. The plume of the Grand River appeared to be much larger than the Campbell Plant plume, on both the thermal images and the multispectral images.

The reduced multispectral data show water masses with different spectral characteristics (differences in color, turbidity, etc.). Water on the inshore side of the thermal bar had decidedly different characteristics than the offshore water. Also, the water masses associated with the Grand River had rather sharply defined boundaries, whereas the Campbell Plant water-mass boundaries were ill-defined. "In general, there was very little mixing of water masses on the shore side of the bar. Since the wind on this particular day was less than 5 mph, this was not surprising."[110]

The data of May 7, under somewhat stronger wind conditions, indicate a considerable amount of mixing on the inshore side of the bar. Again, there was no apparent indication of the Grand River or Campbell Plant plumes interacting with the thermal bar. (It was 2 miles further offshore.) "The map of different water masses along the shore for May 7 emphasizes the complex environment in Lake Michigan and the danger of drawing conclusions from only a small number of samples.

"Observing the results from the two dates (April 30 and May 7) we note that there is not a characteristic water mass traceable solely to the existence of the power plant plume, while the plume of the Grand River is distinctly outlined and the boundary of the thermal bar is also evident. That an algae growth difference (and, therefore, spectral differences) across the thermal bar exists has been documented and reported by Stoermer.[111] The outfall of the Grand River is also known to contain nutrients, pollutants, and sediments which characterize its color. Since the power plant discharges water that has been recycled with only heat added, it seems reasonable to expect no change in the water's spectral characteristics."[110]

Rodgers has reported on thermal-bar measurements in Lake Ontario during the spring of 1970.[101] Weekly temperature profiles were measured at 30-60 stations from May 11 to June 24, 1970. Calculations of heat-content changes in various portions of lake water (due to surface heating, advection, etc.) indicated higher than average heat-content changes near the thermal bar. "Very large positive heat content changes take place in the middle of the lake during the last one to two weeks, in the presence of the thermal bar, associated with small, even negative changes in heat content along the north shore. It is with a reasonable degree of confidence that it can be said that the differences in heat content change (between shore and mid-lake) in the latter stages must be due to offshore advection of heat."[101]

The speed of movement of the thermal bar was inversely correlated with the slope of the lake bottom. Between May 11 and June 8, the thermal bar moved away from the north shore of Lake Ontario at an average speed of 0.43 mile/day. The speed away from the south shore was 0.22 mile/day. During the week of May 19-25, however, the bar actually moved shoreward by a distance of 1½ to 2 miles. "Clearly, there are substantial perturbations in the general offshore progression of the bar."[101]

In a study of the effect of the thermal bar on the concentration of several chemicals in Lake Ontario, Weiler and Coker,[123] during May 1970, measured pH, conductivity, dissolved oxygen, calcium, alkalinity, inorganic carbon, total phosphorous, chlorophyl _a_, silicon, nitrate-nitrogen, and trace metals on both sides of the bar. They summarized their results as follows: "Discriminant analysis shows waters inside and outside the bar are chemically distinct with respect to some of the nutrients. These differences in nutrients are caused by the greater biological activity in the warmer waters inshore of the bar. However, the bar apparently has no effect on the water composition as far as the major ions are concerned. The evidence for the trace elements is not conclusive."[123]

The role of the thermal bar in containing health-oriented bacteria to the inshore area was investigated in two preliminary studies in Lake Ontario during May 15-22, 1970.[83] By measuring coliform, fecal coliform, bacterial biomass and 20°C plate counts in one test, and measuring the diffusion of a tracer bacteria, _Serratia marcescens_, Menon _et al_. concluded that "sufficient data have been collected to suggest that the thermal bar has significant effect on the distribution of bacteria in the lake."[83]

They also stated, however, "The single recovery of _S. marcescens_, although suggestive, is not sufficient evidence to support our hypothesis of the thermal bar's barrier effect to the offshore movement of bacteria. One possibility which must be considered is whether or not the offshore movement of the thermal bar is greater than the diffusion rate of the tracer organism. If such was the case, the diffusion of the tracer organism would never be affected by the thermal bar and eventually would be diluted beyond recovery."[83] Furthermore, the tests were not made in the absence of the thermal bar for purposes of comparison.

B. Biological Characteristics

In aquatic ecosystems there are natural fluctuations both spatially and temporally, in biota and physicochemical conditions. In addition, there is a natural progression of lakes toward eutrophication. To distinguish between changes due to natural factors and those due to man, it is necessary to acquire and analyze data, both before and after man's activities, in sufficient quantity and quality to allow such determinations to be made.

Reference 5 provides an elementary summary of the Lake Michigan ecology. "Although Lake Michigan is showing signs of eutrophication and major changes have occurred in the fish populations, the lower levels of the food chain appear to be relatively unchanged from that generally described by Bersamin[15] in 1958 ... . The productivity of fish population is highly dependent on the productivity of crustaceans in this lake. A generalized food chain for Lake Michigan would be: production of green algae, primarily diatoms, which are grazed by crustacean zooplankters. These crustaceans are in turn grazed on by plankton feeders, which include nearly every species of fish in Lake Michigan, at least during some phase of their life history. Many of these fish species later become piscivorous (fish eating) and feed on other fish species when they reach a certain size."[119] Figure 2 depicts the general trophic structure for the lake at present.

1. Fish

The recent history of Lake Michigan has seen a drastic species change in the fish population. A summary of the commercial production[50] from 1879 to 1968 shows a drastic reduction in lake trout, lake white fish, and lake herring, fluctuations in smelt, and an increase in bloater and particularly in alewives.

Historically, the Lake Michigan offshore waters had a fish population dominated by lake trout, lake white fish, lake herring, bloater, and burbot. Brown and rainbow trout were also present, but these normally used streams for spawning, and it was there that most were available to sports fishermen. In the shallower, inshore waters, the white fish, lake herring, yellow perch, a number of species of small suckers, minnows, and darters were found. All of these fishes were subject to substantial year-class fluctuations due to natural causes, such as very successful or unsuccessful spawns, species competition, and species interactions.

In about 1936 the predatory sea lamprey was introduced into Lake Michigan from below Niagara Falls. Predation by the sea lamprey, added to that of man, reduced the population of large fish such as lake trout and the lake white fish to a point where commercial lake-trout fishing was virtually abandoned. The alewife and smelt were also introduced, and with the top predators having been reduced by predation, the alewife exploded into huge population densities in the mid-60's.

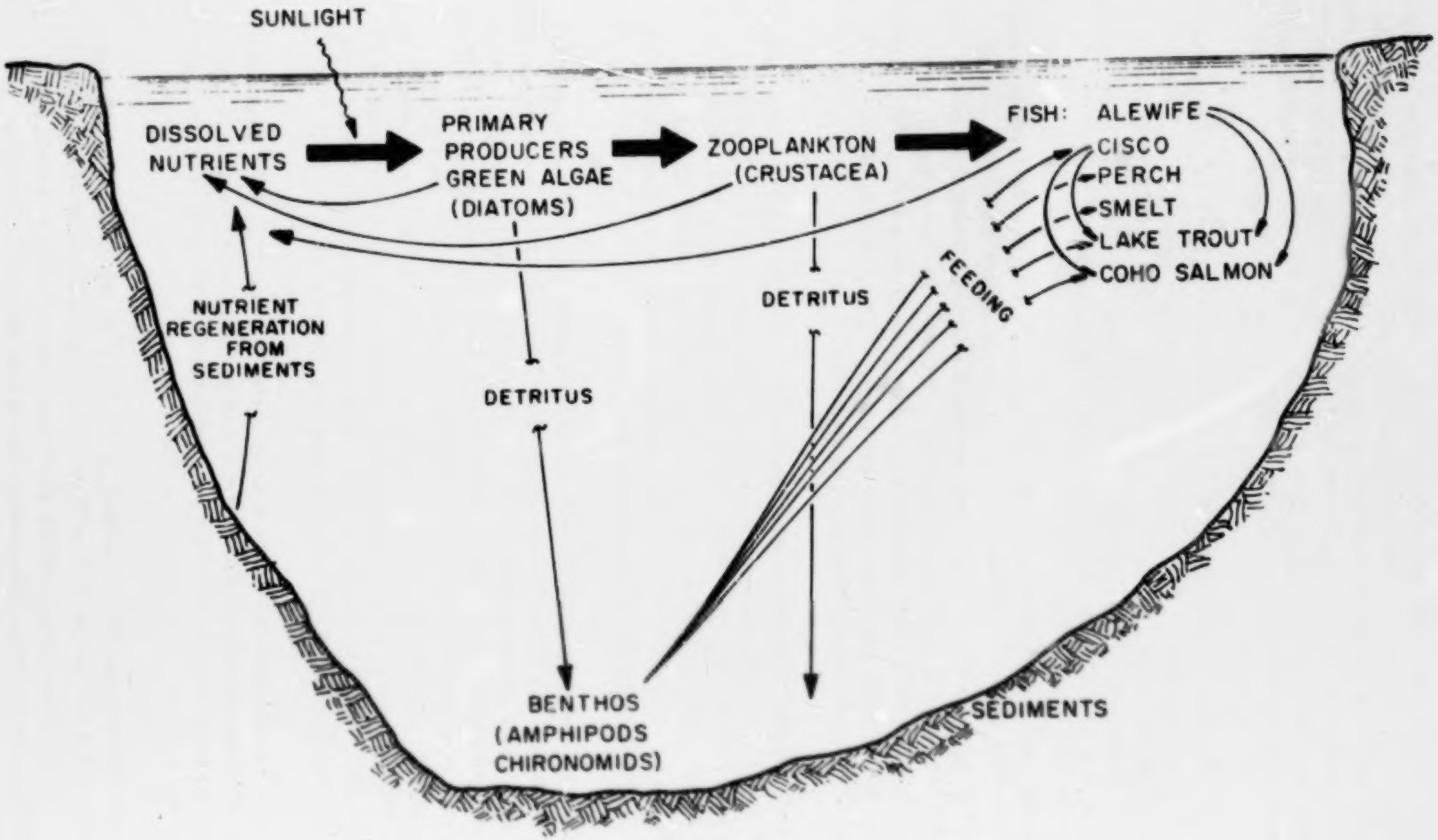


Fig. 2. Generalized Schematic Model of the Trophic Structure of Lake Michigan[119]

In the late 60's the coho salmon was introduced into the system as a top predator. It is now a locally important sport fish. More recently, other predators such as chinook salmon, sockeye salmon, steelhead, splake (a trout hybrid), and lake trout have apparently been successfully stocked. Some fish taken recently show signs of scarring, indicating that the lamprey is still present, although reduced by the many control methods.

A thorough summary of the life histories, migratory patterns, spawning habits, temperature preferences, etc., of the principal fish of Lake Michigan is presented in Appendix V-2 of the final Environmental Statement of the Palisades Nuclear Generating Plant.[119] Table 2 summarizes the ecology of some of the important Lake Michigan fish.

In the immediate Zion-Waukegan area, commercial fishing was reported to be nonexistent.[26] Historical records of catch activity indicate that most fishing takes place 9 miles or more offshore. Fish that are commercially important in the general area are bloaters, yellow perch, and smelt. Forage fish, which also inhabit the area, are important to the support of both the sport and commercial fisheries. The most abundant is the alewife. Sport fishing in this area is very popular.[26]

Commercial fishermen have reported 21 fish species near the Zion area. Of these, 15 species were captured by gill nets and minnow seining during field tests by Bio-Test Laboratories between March and October 1970.[26] Seventeen species were collected from April through December 1971 by minnow seining in the inshore areas in conjunction with studies of the Waukegan station intake and discharge.[72]

The two most abundant fishes taken during the 1970 test period were the alewife and the yellow perch. Other fairly common specimens were the smelt, bloater, and spottail shiner.[26,73] The coho salmon was the most frequently taken salmonid game fish. Statistical data on the weight, length and sex of the various species versus location of capture are given in Ref. 73. In a number of instances, particularly for the alewife, spottail shiner, smelt, and yellow perch, considerably more females than males were taken from the inshore areas at both Waukegan and Zion. Immature individuals were most commonly taken along the shoreline.[73]

The most abundant species near Zion during the 1971 tests were the alewife and spottail shiner. Emerald shiners, bloaters, longnose dace, and smelt were present in low numbers intermittently throughout the summer and fall of 1971.[72]

Stomach-content data for fish collected in the Zion-Waukegan area were summarized in Table VIII of Ref. 73. The salmonids fed most frequently on forage fishes, especially alewives. Amphipods, probably Pontoporeia affinis, were important food items for the white sucker.

Table 2

Ecology of Some Important Lake Michigan Fish (1)

Species	Life Stage	Fall	Winter	Spring	Summer	Principle Food Source (2)
Alewife	Adult	Deep water	Deep water	Warm shallow water at 80' - 85' depths	Warm shallow water. Spawn at 60-82^{o}F in streams and unprotected lake shores. Return to cooler waters after spawning.	Zooplankton
Whitefish	Adult	Shallow water. Spawn in 3'-15' depths on current swept gravels and sands of 42^{o}F.	Deep water	Warm shallow water	Deep water	Insect nymphs and larvae
	Juvenile				School at 8'-10' depths	
Cisco	Adult	Deep water. Spawn in December at 30'-90' depths at 34^{o}-37^{o}F	Deep water	Deep water	Deep water	Zooplankton Daphnia Diaptomus Rotifers Crustaceans Cyclopodia Calanoida
	Juvenile			Hatch at 45^{o}F	School of 8'-10' depths at 58^{o}-65^{o}F	Crustaceans Cyclopodia Calanoida Hapticoida

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(1) Coutant, C.C., Thermal Pollution - Biological Effects, J. Water Pollution Control Federation, 43:1292-1334, 1971

(2) Anderson, E. D. and L. L. Smith, Jr., A Snyoptic Study of Food Habits of 30 Fish Species from Western Lake Superior, Tech. Bull. 279, Minn. Agric. Expt. Sta., St. Paul, Minn. 1971

Table 2 (continued)

Species	Life Stage	Fall	Winter	Spring	Summer	Principle Food Source (2)
Perch	Adult	Deep water	Deep water not less than 60'	Shallow water less than 40' deep. Spawn in weeds and rocky shallows at 45°-54°F	Deep water > 60'	Insect Larvae and Nymphs Cladocerans *Daphnia* *Sida* *Halopedia* *Alona* Amphipods-*Gammarus* Snails Sphaeridae Copepods, Water mites, Ostracods, Isopods, small fish (Alewife, Smelt)
	Juvenile				Shallow water 3'-18' depths	Similar to adult fish
Bloater	Adult	Deep water	Deep water. Spawn in 120'-180' depths	Shallow water	Deep water at 46°-50°F	Crustaceans Cladocerans Copepods *Pontoporeia* *Mysis*
	Juveniles				Deep water at 50°F	Gastropods-*Valvata* Sphaeridae Sculpin and Bloater Eggs

Table 2 (continued)

Species	Life Stage	Fall	Winter	Spring	Summer	Principle Food Source [2]
Smelt	Adult	Shallow water at 72' depths	Shallow water	Shallow water and streams for spawning at 50°F	Deep water	Aquatic insects Crustaceans Copepods Cladocerans Mysis Amphipods-Gammarus Pontoporeia
	Juveniles					Rotifers Cladocerans Copepods Small eggs
Trout	Adult	Deep water 120'-300' depth at 50°F. Spawning in a few inches to 100's of feet depth	Deep water 120'-300' depth at 50°F	Deep water 120'-300' depth at 50°F	Deep water 100'-300' depth.	Fish of all sizes
	Juveniles					Crustaceans (Mysis) Insects Small fish (Sculpin)

sculpins, and the one white fish that was collected. Although Pontoporeia has been reported as an important food for alewives and occurs commonly in the area, it was not heavily used by the alewives captured in the study. Shoreline minnows, white suckers, and smelt fed heavily on chironomid larvae. Yellow perch and smelt fed more frequently on forage fish in the Waukegan area than at Zion. Zooplankton (cladocerans and copepods) were used by more fish at Waukegan than at Zion, except for the alewife.[73]

The relative frequency of fish eggs in the stomachs of nine species showed a rather wide utilization of fish eggs for food. The fish eggs were probably the eggs of more than one species, since they were found over such a long period, from March through October. Alewives, smelt, and perch were found in the area during their anticipated time of spawning, and the eggs of these species were probably among those commonly found in the stomachs.

Reference 122 states "Although no direct data exist, it is questionable if the waters off the Zion site could provide grounds suitable for spawning of any fish on a large scale due to the ever-present scouring action of waves. Spawning presumably occurs in protected harbors where there are quiet waters." Bureau of Sport Fisheries and Wildlife records[42] for various fish spot-checked by trawling at 3-40 fathom depths off Waukegan from 1967 to 1971 (October, November, April and May) suggest that, except for smelt, alewife and bloater, the ratio of young to adult is much less than 50%.[122]

Plankton net tows have shown that this area does not contain significant amounts of either fish larvae or pelagic fish eggs, yet analysis of stomach contents suggests that spawning of some species may take place.[73]

Supplement IV of the Zion Environmental Impact Report[27] states, "Based on preoperational monitoring accomplished thus far, it appears fairly certain that spawning grounds for lake trout and white fish do not exist in the Zion area. Preoperational studies have shown that adults of these species are absent from the predicted area of discharge during spawning season."

Recent collections by state fisheries and game personnel have shown the species of fish listed in Table 3 to be present at the Point Beach and Kewaunee area.[98] This was confirmed by gill-net sampling by Bio-Test Laboratories in 1971.[70]

The most abundant sport fish found in the area during 1971 was the lake trout.[70] Virtually all had been stocked in Wisconsin waters by Federal or State agencies, as indicated by their clipped fins. The bulk of the fish taken were year-class V (1966) fish. They were predominant in the spring and fall; year-class III and IV fish were more in evidence during the summer months.

Table 3

Fish Species in Lake Michigan Near the Kewaunee Site

Rainbow trout
Brook trout
Brown trout
Lake trout
Coho Salmon
Fathead minnows
Shiners
Dace
Round whitefish
Lake whitefish
Yellow perch
Alewife
Sculpin
Smelt
Longnose suckers
Bloater chub
Carp
Suckers

Stomach analysis of the lake trout revealed alewives comprised 57%, by volume, of the total food items. Other items included smelt, shiners, and sculpins. A large number were taken with empty stomachs. This occurred during October 1971, when they were near spawning conditions.[70]

Reference 129 states there are no known spawning or nursery grounds for fish in the area of the Point Beach Power Plant site. Samples taken from the Point Beach discharge flume by the Wisconsin Department of Natural Resources, between March and May 1971, resulted in a total catch of eight sculpin, two samples with a "few" smelt eggs, and one possible salmonid egg.[129]

During a 3-yr period (1968-1970) of preoperational surveys conducted by the State of Michigan[96] in the area of the Palisades Plant, 28 species of fish were captured by gill netting, seining, or trawling. Gill-net catches were dominated by alewives (55%) and yellow perch (39%). Shoreline seining disclosed a predominance of longnose dace and spottail shiners. Aside from alewives, the trawl catches were composed principally of smelt, trout, perch, and bloaters. Among the salmonids, the total catch for 3 yr was 32 lake trout, 8 coho salmon, and 10 chinook salmon, nearly all of which were from plantings made at nearby Port Sheldon and New Buffalo.[96] There were significant diurnal differences in the catches.

Perch was the most abundant game fish sampled throughout the summer and fall. Since no young-of-the-year perch were captured, it was postulated that they were inhabiting the zone 3-18 ft deep, an area that was not sampled.[96] Very few adult alewives were taken in the inshore area during daytime seining, but large numbers were captured at night on May 14, 1970.

Bloaters were the only species of Coregonus caught in any abundance during the 3-yr period. Only four lake herring were taken during the test period.

A Great Lakes Fishery Laboratory cruise report[19] described fishing to locate spawning grounds of lake trout and white fish in southeastern Lake Michigan. "Catches (during November 1971) of ripe, spent, and gravid female lake trout in several areas off Benton Harbor (D. C. Cook Plant site), South Haven (Palisades Plant site), and Saugatuck suggest that this species spawned in large numbers along the entire southeastern shore of Lake Michigan. All males were in spawning condition. Of 183 fish over 23 inches long, 31% had healed lamprey scars and 1.1% had fresh wounds.

"The only whitefish taken were a single female off New Buffalo and 6 ripe males off Saugatuck. The evidence ... suggests that whitefish spawn in suitable locations (probably mostly reefs) along the southeastern

Lake Michigan shore, but not in great numbers. Fairly large catches of lake trout were made off New Buffalo and Saugatuck in the December nets. Nearly all were males."[19]

Fish, taken inshore at the Bailly Plant site (September 19-20, 1970) by seining, included about 200 yellow perch, less than 3 in. long, several small bluegills, two small largemouth bass, and several species of unidentified minnows.[91] Fish taken in gill nets included 88 yellow perch, two white suckers, and one longnose sucker. Yellow-perch age groups were III, IV, V, and VI with twice as many females as males. The perch were feeding primarily on crayfish (from extensive areas of rip-rapping in the area) and other fish.

Additional fish data specific to the Cook Plant area are given in Ref. 65. A tabulation of the 1970 catch data for game fish taken off of Berrien County, Michigan (site of the Cook Plant), revealed the following abundance percentages: smelt, 62%; perch, 31%; chinook salmon, 6%; and trout (lake, brown, rainbow, and steelhead), 4%.

2. Plankton

Generally, Lake Michigan has low algae populations compared with those of most surface waters, with centric diatoms predominating.[14] During the summer, however, the southeast sector of the lake contains algae close to the shoreline of the type commonly found in eutropic situations.[87] There is an apparent relationship between the areas of the lake shore, where nuisance algae occur, and the proximity of sources of plant nutrients contributed by major tributaries.[119]

The background data on plankton in the Zion-Waukegan area were summarized as follows:[26]

"Water samples for plankton counts were collected in the Zion area in April 1968, and in August, October and December 1969, and monthly since. Despite a problem in comparing population because different sampling techniques were used, the species of plankton identified in the spring of 1968 were similar to those of 1969 and subsequent studies ... .

"In August 1969, the plankton population near Zion was composed of green algae, blue-green algae, diatoms, protozoans, and crustaceans with the diatoms usually comprising more than 80 percent of the total plankton. This plankton population was not evenly distributed in the water column but was most numerous at the 15 to 20 foot depth.

"In October 1969, the total plankton population was similar in composition to that observed in August. Diatoms usually comprised more than 75 percent of the total plankton population at all depths sampled. In addition to members of the genera Fragilaria and Tabellaria, species of Asterionella were observed more frequently in the October samples. Although temperatures were similar throughout the water column, the plankton populations were most numerous at the 10 to 13 foot depth.

"Plankton samples taken during December, 1969, were obtained from a much wider section of the lake than earlier samples and are therefore believed to more accurately represent the existing population. Most of the samples were taken between the 5 and 15 foot depths, ... The total population was composed of the same planktonic forms observed in August and October, 1969; however, the diatoms comprised more than 90 percent of the population (rather than 75 percent). The diatoms Tabellaria and Fragilaria were still represented; however, species of Stephanodiscus replaced Asterionella as a dominant form.

"The 1970 and 1971 studies to determine the thermal effects on both phytoplankton and zooplankton found in the Waukegan area produced comparable data on planktonic population to those in the Zion study. With respect to phytoplankton, these more extensive studies confirmed earlier observations and led to the conclusion that most species encountered were classical to Lake Michigan, however, the diatom Stephanodiscus hantzschii-tenuis was a notable exception. It was found to be the most dominant species in April, May and June and has been associated with organic enrichment (Stoermer and Kopczynska,[112] 1967).[71] This species also represents more than 5 percent of the August and September populations."[26]

It should be noted that the relative abundance of diatoms measured by the Industrial Bio-Test Laboratories in the Zion-Waukegan area in August, October, and December 1969 (80, 75, and 90%, respectively), contrasts sharply with the data of Schelske and Stoermer,[107] which indicated that diatoms comprised 10% of the phytoplankton samples taken from the midlake part of southern Lake Michigan during the summer of 1969.

A more detailed reporting[69] of plankton samples obtained in the Zion-Waukegan area from April to December 1971 revealed the following: Chrysophyta (golden-brown algae) was the most abundant algae division. Diatoms, the most numerous of which were Fragilaria crotonensis, Stephanodiscus binderanus, S. hantzschii-tenuis, Rhizosolenid eriensis, Asterionella formosa, and Tabellaria flocculosa, comprised more than 90% of the April-August population, about 50% of the September-October population, and more than 70% of the November-December population. The Cyanophyta (blue-green algae) was the second most abundant, the percentages ranging from 0.2 to 42% of the phytoplankton. Chlorophyta (green algae) had an abundance of 0.2-7.6% of the total phytoplankton.

The largest standing crops of diatoms were observed in April, May, and June when temperatures were below 56°F, with inshore waters containing more than offshore waters. The temperatures at this time were above what is considered optimum for several of the dominant species.[69]

Comparison of Chrysophyta populations with the concentrations of silicon dioxide, total phosphate, and nitrate-nitrogen revealed (a) that silica increased gradually in the spring and then declined concurrently with decreasing diatom populations during August (the quantity of silica generally declines as diatom populations increase), (b) total phosphates decreased gradually from June through October, and minimum amounts coincided with the fewest diatoms, (c) nitrate-nitrogen remained uniform from May through September and increased during the fall (this may be attributed to a reduced uptake of nitrates by phytoplankton during a period of minimum population growth).[69]

The blue-green algae comprised less than 5% of the phytoplankton from April through August 1971. However, from September through December, percentages at various sampling locations varied from 11 to 67% of the phytoplankton, primarily due to an increase of *Collosphaerium naegelianum*. It was noted that blue-green algae populations did not exceed 25% of the total during the 1970-1971 study.

Zooplankton data acquired by the Industrial Bio-Test Laboratories were summarized[26] as follows: "Additional data on zooplankton, also obtained in 1970 and 1971 studies, revealed that the most common classes present in Lake Michigan near the Zion station were copepods, cladocerans and to a lesser extent, rotifers. The most abundant zooplankton crustacean in Lake Michigan, the *Cyclops bicuspidatus thomasi*, was found to be the dominant species representing the copepods. Other common copepods ... were *Eurytemora affinis* (present in large numbers in September and October), *Cyclops vernalis* (quite common in October and present in low numbers in September), and *Diaptomus ashlundi* (found in moderate numbers in January and December and again only in significant numbers in September). The most abundant Cladocera throughout the study was found to be the *Bosmina longirostris*. *Daphnia retrocurva* and *Ceriodaphnia quadrangula* were also present in significant numbers in August. Rotifers were represented predominantly by *Conochilus* and *Asplanchna priodonta* ... ."[26]

A more detailed reporting[69] of zooplankton studies in 1971 stated that a seasonal variation was clearly observed. "The major portion of the zooplankton community was composed of copepods during the spring months. Then, with the higher water temperatures of July through September, the cladocerans predominated. As the water temperature decreased, the copepods again predominated."[69]

Plankton samples obtained at the Kewaunee site in 1971[70] revealed that diatoms were the most abundant members of the phytoplankton, followed by blue-green algae and green algae. The diatoms were most abundant in May (91%), and the fewest numbers were observed in November (66%). Blue-green algae comprised 2-26% of the population, the lowest and highest values occurring during May and November, respectively. The larger counts were due to an increase in *Coelosphaerium naegelianum*. Green algae and miscellaneous forms always accounted for less than 8% of the total. These results are similar to the Zion studies.

The five most abundant species were *Fragilaria pinnata*, *F. crotonesis*, *Tabellaria flocculosa*, *Coelosphaerium naegelianum*, and *Stephanodiscus hantzschii-tenuis*. All are diatoms except the blue-green algae *C. naegelianum*.

Zooplankton samples were obtained in the Point Beach and Kewaunee areas by The University of Wisconsin-Milwaukee[126-128] and at Kewaunee by Bio-Test Laboratories.[70] The Bio-Test data identified 13 species of cladocerans, 11 species of copepods, and two immature stages of copepods during 1971. This included small numbers of five genera not reported in The University of Wisconsin data of 1969[126] and three genera not reported in the 1971 data.[128]

The most numerous species identified in the Bio-Test studies at Kewaunee were *Bosmina longerostris*, *Chydorus sphaericus*, *Cyclops bicuspidatus thomasi*, and two species of *Daphnia*; The University of Wisconsin data from Point Beach and Kewaunee listed *Bosmina*, *Cyclops*, *Diaptomus*, *Daphnia* and rotifers as the most abundant. Both studies found numerous copepod nauplii. The rotifer population was reported to be much higher in 1971 than in 1969 and 1970.[128,70]

Dr. Ayers conducted limnological studies at the Cook Plant site in 1969 and 1970. On July 10, 1970, phytoplankton samples were obtained at 53 stations. The 53 samples contained 59 dominant or codominant (six stations had two species of approximately equal numerical superiority) groups, of which 49 were diatoms.[7] The number of samples in which the various species were dominant are *Tabellaria fenestrata* (32), *Cyclotella* sp. (seven), *Milosira* sp. (six), and *Fragilaria crotonensis* (four). The species *Milosira* sp. and *Cyclotella* sp. were most dominant in the surf zone, and *F. crotonensis* was more dominant in stations farthest offshore.

The investigators made the following comments concerning their data:[5]

a. "There appears to be an increase (in numbers of species, at least) of blue-green algae from spring into fall.

b. Green algae appears to have a peak in late summer that may or may not be supported by subsequent data.

c. The persistence of flagellates is unexpected and may or may not be supported by subsequent data."

Examining their data for river-associated phytoplankters, they concluded that the evidence from the July 10 survey shows no demonstrable effect of the St. Joseph River on the Cook Plant phytoplankton.[7]

Variations from station to station in the diversity index, number of species, and organism density, during the July 10, 1970, tests forced them to conclude "that small water masses, each with different biotic characteristics, move through the Cook Plant area."[7]

Zooplankton data obtained on July 10, 1970, also indicated a patchiness from station to station, but it was not as pronounced as phytoplankton patchiness. Although the Cyclopoid copepods were occasionally present in the greatest numbers, Bosmina cladocerans dominated the samples most frequently. The most abundant zooplankters had the following sample frequencies: Cyclopoid copepods (eight), Diaptomus copepods (none), Bosmina cladocerans (37), Polyphemus cladocerans (two), and Asplanchna rotifers (none).[7]

Copeland and Ayers[34] provide an interpretation of biological data obtained during lakewide sampling during 1969 and 1970. "Inspection of the phytoplankton data tends to confirm the general trends observed in other studies. In general, total phytoplankton abundance was greater near the south end of the lake and near shore than in the northern end and in the central lake. This was the expected situation. However, relative abundance of the various algal groups did not follow the expected pattern. In only about half of the samples did diatoms represent more than half the algal cells present. Their relative abundance was lowest at some of the open lake stations, particularly toward the northern end. When diatom abundance was low, the green algae usually were found to be high, and vice versa. The other groups tended to remain at rather low levels except for an occasional peak in the blue-green's and dinoflagellates, but these peaks seldom represented more than 50% of total phytoplankton. Since phytoplankton abundance can rise and fall rather quickly, and since samples from different stations in this study were widely spaced in time, even within a single cruise, it is unwise to draw any more detailed conclusions from this data."

Copeland and Ayers[34] interpret zooplankton data obtained during lakewide sampling in the following manner. "Comparison of the zooplankton data with other studies is particularly difficult because of differences in sampling techniques and schedules used by various investigators. The list of species present was as expected, and few anomalies were present in their relative abundance. Either the Calanoid copepods (especially Diaptomus) or the Cyclopoid copepods were usually the most abundant group, although they were outnumbered in a few samples by Daphnia. Total zooplankton abundance fluctuated greatly from sample to sample, and no clear temporal or geographic trends could be seen."

3. Periphyton

"Periphyton are defined as the complex assemblage of aquatic organisms, especially green and blue-green filamentous algae, that grow attached to permanent substrates such as rocks, logs, steel pilings, etc. in shoreline areas. In addition to the larger algae, there are less obvious diatoms, many bacteria, protozoa, and invertebrate animals which constitute the periphyton community. Under normal conditions periphytic growth is considered to be beneficial because it is a food source to many fish or fish food organisms. Some of the bottom feeding fish, such as carp and suckers, will browse directly on the filamentous algae. Forage fish feed on the protozoa and invertebrates. As the algae die and decompose, the organic material released becomes nutrients for other algae and invertebrates, all of which constitute the aquatic food chain of the littoral area.

"It is only when the periphyton growth exceeds the rate at which fish and invertebrates can assimilate it into the normal food chain that the growth becomes excessive and a nuisance. Excessive growth can create problems, both aesthetically and practically, when the filamentous algae break away and float onto beaches to decay, enter municipal waterworks, or clog equipment maintained in the lake."[74]

Periphyton samples, collected from natural substrates in the Zion area in 1969 (no month given), indicated that the filamentous green algae, *Cladophora*, was the most common organism in the periphyton community.[28]

A more thorough study[74] summarizes the results of periphyton samples collected from April 1970 to March 1971 from both permanent and artificial substrates near the Zion Station and the Waukegan Station. Periphyton growth was measured from May until November, at which time a combination of ice, water temperature less than 50°F, and stormy weather inhibited growth.

Permanent substrate growths were characterized by the cold-water genera *Ulothrix* and *Stigeoclonium* in the spring and *Cladophora* in the summer. *Cladophora glomerata* dominated during July and August and was found on most substrates through October, at which time *Ulothrix zonata* reappeared. The appearance and disappearance of diatoms and blue-green algae had no such clear-cut trend.[74]

The cold-water genera *Ulothrix* and *Stigeoclonium* grew abundantly on artificial substrates before the appearance of *Cladophora*. *Cladophora* first appeared on the artificial substrates at Zion in June, became abundant in July, and disappeared in August. *Ulothrix* was the most abundant green algae in the Zion area from August through November.[74] The Waukegan intake supported *Cladophora* during July and August, although it was not abundant.

Cladophora persisted on the permanent substrates until October, but its growth on the artificial substrates occurred only during July and August. This differential persistence demonstrated the value of studying both substrates.[74]

Abundant diatom growth of several species occurred near Zion during the entire sampling period. In contrast, abundant growth at the Waukegan intake occurred only during spring and summer months and was limited primarily to two species. The data indicate that diatoms have a limiting upper temperature for maximum growth between 55 and 70°F, with a sharp inhibition at temperatures above 70°F.[74]

The Zion area did not support abundant blue-green algae growth during any season. Abundant growth in the Waukegan intake was restricted to the period from July to October. The report postulated that blue-green algae growth is not expected to increase near Zion after startup because the underwater, offshore discharge is designed to prevent warm water from reaching the nearshore substrates suitable for periphyton growth.

Chlorophyl *a* and biomass data indicate the largest amount of periphyton growth on *artificial* substrates was supported in the Waukegan intake canal during August and September. The water temperatures were between 67 and 70°F. After September, periphyton growth was greater on *artificial* substrates in the Zion area. Except for an early October chlorophyl *a* analysis, the late September to November growth near Zion was significantly larger than growth in the warmer waters near Waukegan.[74]

Diatoms were the most abundant form of periphyton in the Kewaunee and Point Beach areas. *Fragilaria* was the most abundant diatom represented by nine species. *F. vaucheriae* was the most abundant species in studies using plexiglass substrates,[126-128,131-133] whereas samples from natural substrates near Kewaunee in 1971 showed *F. vaucheriae* to be in low abundance.[70] The difference was most likely attributed to the different substrates. (In general, there is a lack of permanent substrates along the shoreline in that area.)

Bio-Test studies[70] reported periphyton samples taken from wooden pilings and riprap contained strands of filamentous green and blue-green algae intermixed with several species of diatoms. The most obvious species of filamentous green algae was *Ulothrix zonata*, which was more abundant in May and November than in August. (The University of Wisconsin studies were limited to periphytic diatoms.)

There are few results of periphyton studies to report for 1970-1971 that are specific to the southeastern shore of Lake Michigan. Two periphyton samples were obtained from a 6-ft-deep, plastic, subsurface float in October 1969.[5] The samples were only qualitatively examined to determine the dominant periphyton types in the Cook Plant area in the fall. The periphyton were very sparse and were dominated by diatoms of the genera Gomphonema, Nitzschia, Synedra, Achnanthes, and Cymbella. The dominant diatom was Gomphonema sp., though Melosira varians was also quite abundant. One green algae, Stigeoclonium, was present in some numbers. No Cladophora was present.

A very brief tabulation of the dry weight per square meter of approximately one month's growth of periphyton in the Palisades area, during May-August 1969, is given in Ref. 30. No species identification is reported.

Periphyton samples were obtained at the Bailly Station site in September and October 1970. These data were taken in the presence of the thermal discharge from the existing Bailly Plant and therefore will be discussed in Section III below.

4. Benthos

In April 1968 and August, October, and December 1969, bottom organisms were collected off Zion at offshore distances out to 5600 ft. The 1969 samples were generally similar in composition to the samples collected and reported by Beer and Pipes in April 1968.[13] The benthic organisms found in the Zion area were generally dominated by crustaceans, but oligochaete worms were most numerous in the shallower areas. The fingernail clams (Pelecypoda), Sphaeriidae, and the snails (Gastropoda) usually composed less than 15% of the benthos found.[26]

In depths shallower than 10 ft, benthic populations at Zion were almost nonexistent, probably as the result of scouring by wave action and the frequent shifting of bottom sediments. At depths of 10-20 ft, oligochaetes (aquatic worms) became the most abundant organism. Tubificids were the most abundant shallow-water species, and Stylodrilus heringianus was reported as the most abundant deeper-water species. In waters deeper than 20 ft, the burrowing amphipod, Pontoporeia affinis, became the dominant benthic representative.[26]

Samples obtained at Zion from April through December 1970 showed the benthic populations peaking (approximately tripling) during July and August, because of reproduction, and then slowly declining during the fall months. Pontoporeia affinis was the dominant organism, accounting for 50-83.4% of the total population. Oligochaete worms, midges (Chironimidae), and fingernail clams (Sphaeriidae) ranked second, third, and fourth, respectively.[26]

Samples obtained during 1971[69] confirmed crustaceans (Pontoporeia affinis) as the most abundant benthic organism, with population densities similar to those of 1970. Oligochaetes, consisting primarily of tubificids, composed the second most abundant category, with fingernail clams third. Snails and insect larvae together composed only about 10% of the total benthos. The tubificid population density was somewhat higher in 1971 than in 1970. The total benthic population densities varied among various sampling areas, but no clear trends were apparent throughout the year.[69]

Low numbers of benthos were collected during 1971, at depths less than 20 ft, from the clay and rock substratum that underlies the shallow waters near Kewaunee. Chironomidae (midge larvae) was the predominant group of organisms, probably because of its ability to construct cases and avoid being swept away by wave action. Different chironomid genera, with the exception of Heterotrissocladius, were observed each season.[70]

Reference 121 cites (without reference) a brief study of the benthos at Point Beach in 1968: "The Point Beach benthos was so depauperate that use of benthic organisms as indicators (for long range environmental effects) was abandoned."

Benthic samples were obtained at the Point Beach Power Plant at monthly intervals, from May through August 1971 by Argonne National Laboratory.[109] The samples, obtained from depths of less than 40 ft, confirmed that the benthic population was very sparse. Unlike the conditions at Kewaunee, the most common organism collected was the amphipod, Pontoporeia affinis, with population densities of 0-100 organisms/m^2. This density is extremely low compared to data from Zion, where population densities ranged from 4000 to 16,000/m^2 (Ref. 77).

Bottom samples for benthic invertebrates were collected in the Palisades area from May 1968 to October 1970.[30] The benthic samples were typical of those found in Lake Michigan, the major taxonomic groups being amphipods (primarily Pontoporeia sp.), aquatic earthworms (Oligochaeta), freshwater clams (Sphaeriidae), aquatic insects (primarily Chironomidae), flatworms (Turbellaria), leeches (Hirudinea), and hydra (Coelenterata). Densities of the amphipods, oligochaetes and pelecypods increased with increasing depth. Chironomidae were the predominant organisms at depths less than 20 ft.[119]

The abundance of benthic organisms was low in the Bailly region, as compared with other aquatic life in Lake Michigan. Of the organisms present during September and October 1970, oligochaete worms (Tubificidae), comprised 52% of the total benthic organisms. Most of the species of oligochaetes present were characteristic of eutrophic, but not grossly polluted, waters. The two genera of midge larvae present, Chironomus and Cryptochironomus, are characteristically found in eutrophic and polluted sediments. The amphipod, Pontoporeia affinis, is a cold-water form and found only at the station in deepest water.[91]

Ayers found that limited sampling for benthos in the Cook Plant area, during 1969 and part of 1970, was difficult to interpret.[5] In a report[7] on the initial phase of a large-scale sampling program at the Cook site on July 1970, he concluded the benthic macrofauna increased strongly with depth between 15 and 80 ft. Chironomids were present in low abundance over much of the area and dominated the benthos in depths less than about 20 ft.[5]

Reference 34 summarizes lakewide benthos data acquired during 1969 and 1970 in the following way. "The benthos samples were also about as expected from previous studies. In most cases, total benthos abundance was between 1000-5000 organisms per square meter, but it occasionally was much higher. Only 3 stations (Sheboygan, Zion, and 20 miles southeast of Waukegan) had very high benthos abundance, and even these had more normal abundance on at least one cruise. Beeton,[14] in reviewing the work of other investigators, mentioned that the proportions of amphipods and oligochaetes reported in the fauna had shifted from 48/39% respectively to 65/24% between 1931-32 and 1963-64. In the present samples, however, the proportion was nearer to the earlier figures stated above than to the latter. This may be due in part to selection against small forms, especially oligochaetes, by the sampling and sorting process used on the present study."

The lack of benthos in the inshore areas of Lake Michigan was confirmed by Copeland and Ayers[34] in their description of changes in their sampling locations. The station at the Kewaunee Nuclear Plant was moved to 3.5 miles offshore because at 1 mile the sediments were hard and unsampleable with little or no benthos; the Point Beach Station was moved to 4 miles offshore for these same reasons; the Bailly Nuclear Plant station was moved to 2 miles offshore because, while the sediment was sampleable, there was little or no benthos.

III. STUDIES RELATED TO THERMAL PLUMES

A. Physical Characteristics

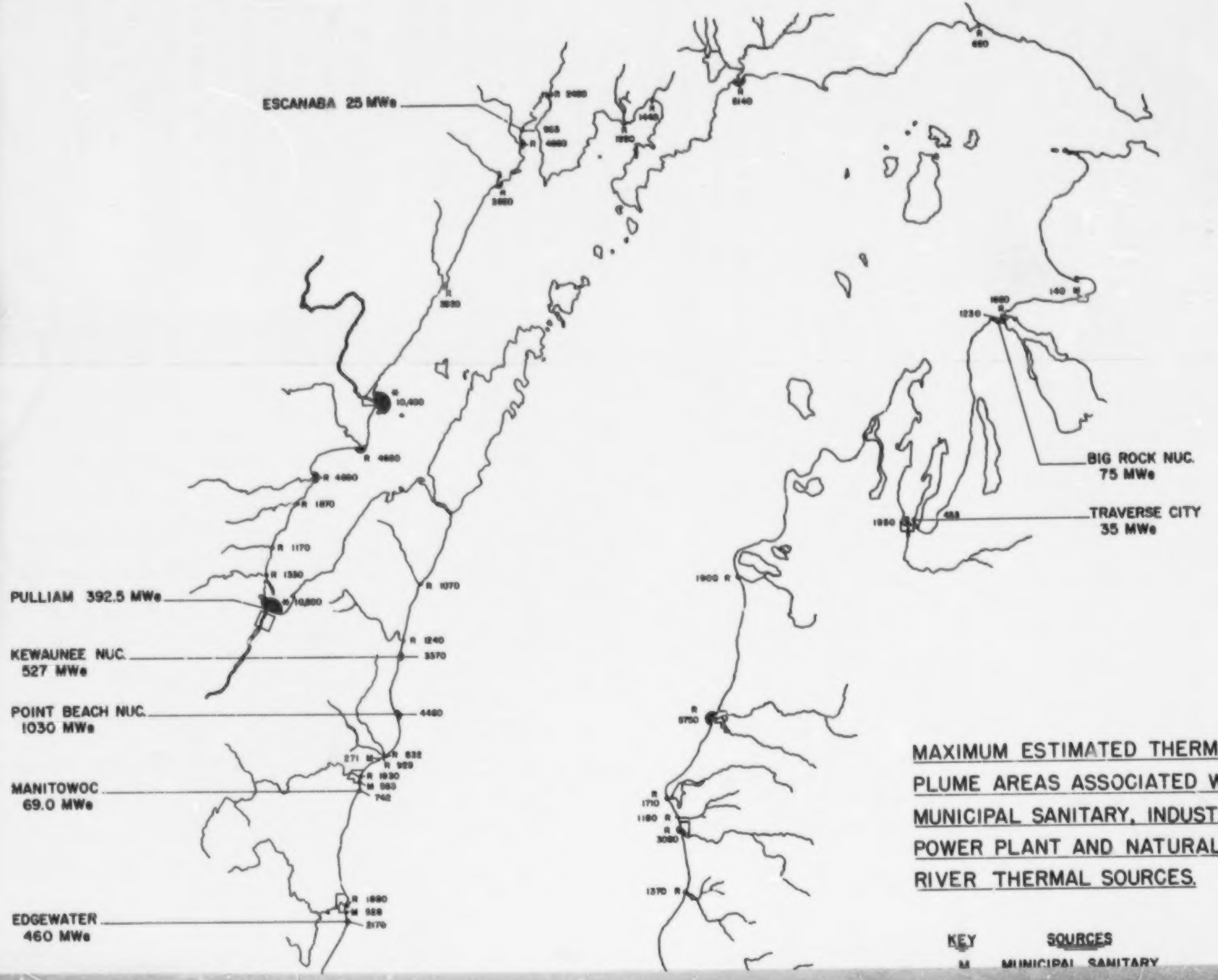
Before one can assess the biological or ecological impact of waste-heat discharges on a particular receiving body of water, it is necessary to first determine the "natural state," biological and physical, of the water body. This matter has been pursued in the preceding section. The next step in evaluating the impact requires the identification of the areal extent and temporal behavior of the temperature changes within the body of water induced by the heated additions. This section lists and briefly reviews those references that have provided this kind of information, either from direct physical measurements or from model predictions. As indicated in the Preface, the reference material will for the most part be limited to subject matter directly related to the Lake Michigan environment.

The major source of heat input into the Lake is, of course, solar energy. Each spring and summer it raises the temperature of large volumes of lake water from 32 to about 70°F. Man obviously has no control over this source. Rivers and streams are also sources of heat input during certain times of the year. Man has some control over these sources by the way he uses them for cooling. He may also increase their absorption of solar energy by impounding them behind dams or by reducing their shade by deforestation. Other significant sources of heat input are, of course, industrial and municipal uses of the water, over which man has complete control.

The lakewide physical effects of man-made thermal discharges (primarily electric-utility generating stations, steel plants, and municipal waste-water treatment plants) have been analyzed by Asbury.[3] The studies showed that if all the waste heat projected for the year 2000 were mixed throughout the lake, the lake surface temperature would have to increase only 0.1°F to dissipate it. The increased evaporation loss would be 810 cu ft/sec, compared to a natural evaporation loss of about 40,000 cu ft/sec.

Figure 3 shows an inventory of the major heat sources for Lake Michigan. It includes major rivers, principal industrial sources, and steam-electric power plants contiguous to Lake Michigan. The black semicircles represent the estimated thermal-plume areas associated with the peak thermal discharges. The plume areas extend from the point of discharge to the place where the heated water cools to 1.8°F above the natural ambient lake-water temperature. The size of each plume was calculated using estimated or known flow and temperature information for a particular source, together with a phenomenological model for predicting plume areas proposed by Asbury and Frigo.[4] River-plume areas were computed from the maximum monthly thermal-discharge rates associated with the rivers

A



MAXIMUM ESTIMATED THERMAL PLUME AREAS ASSOCIATED WITH MUNICIPAL SANITARY, INDUSTRIAL, POWER PLANT AND NATURAL RIVER THERMAL SOURCES.

KEY	SOURCES
M	MUNICIPAL SANITARY

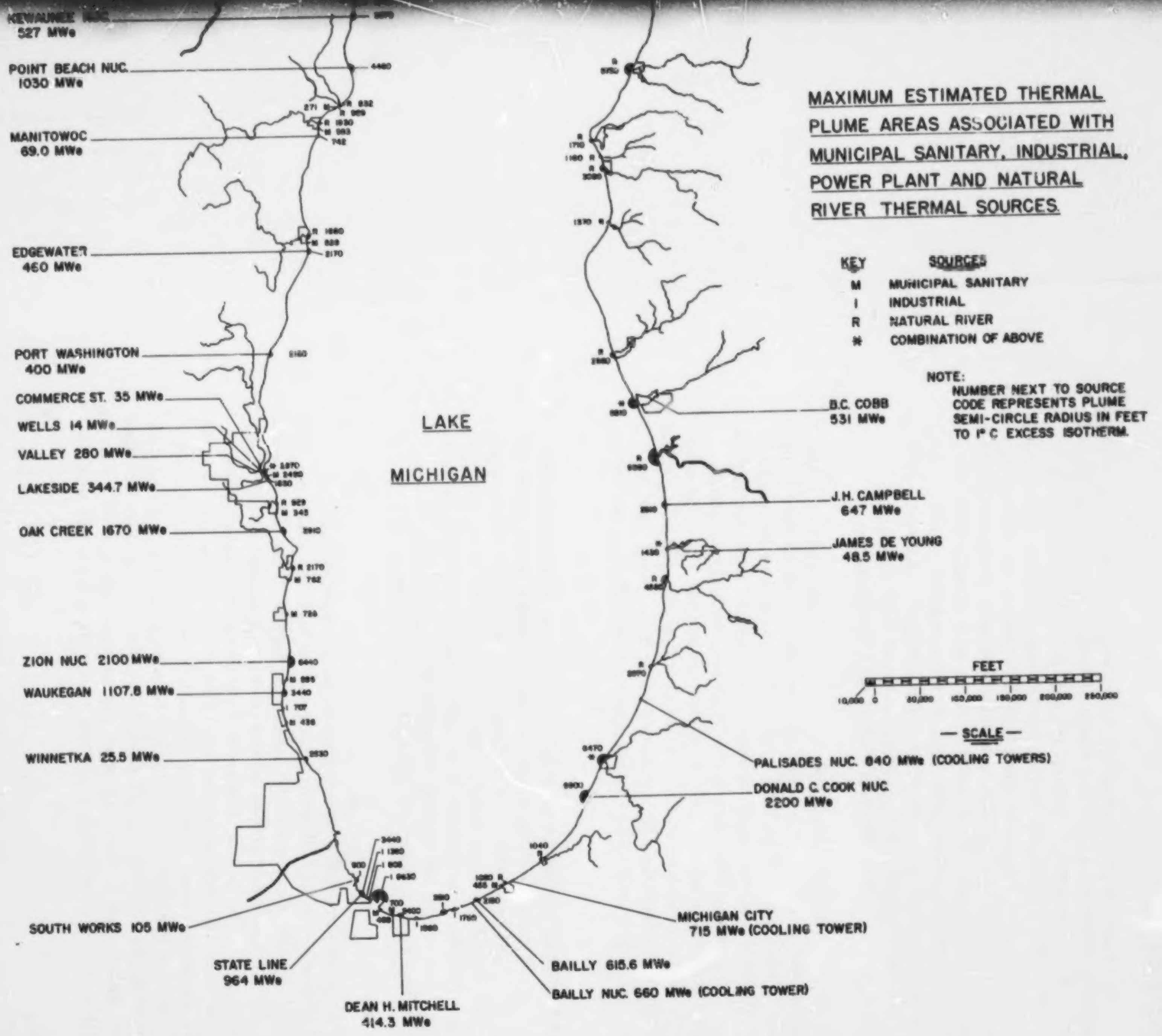


Fig. 3. Maximum Estimated Thermal-plume Areas Associated with Municipal, Sanitary, Industrial, Power-plant, and Natural River Thermal Sources.

B

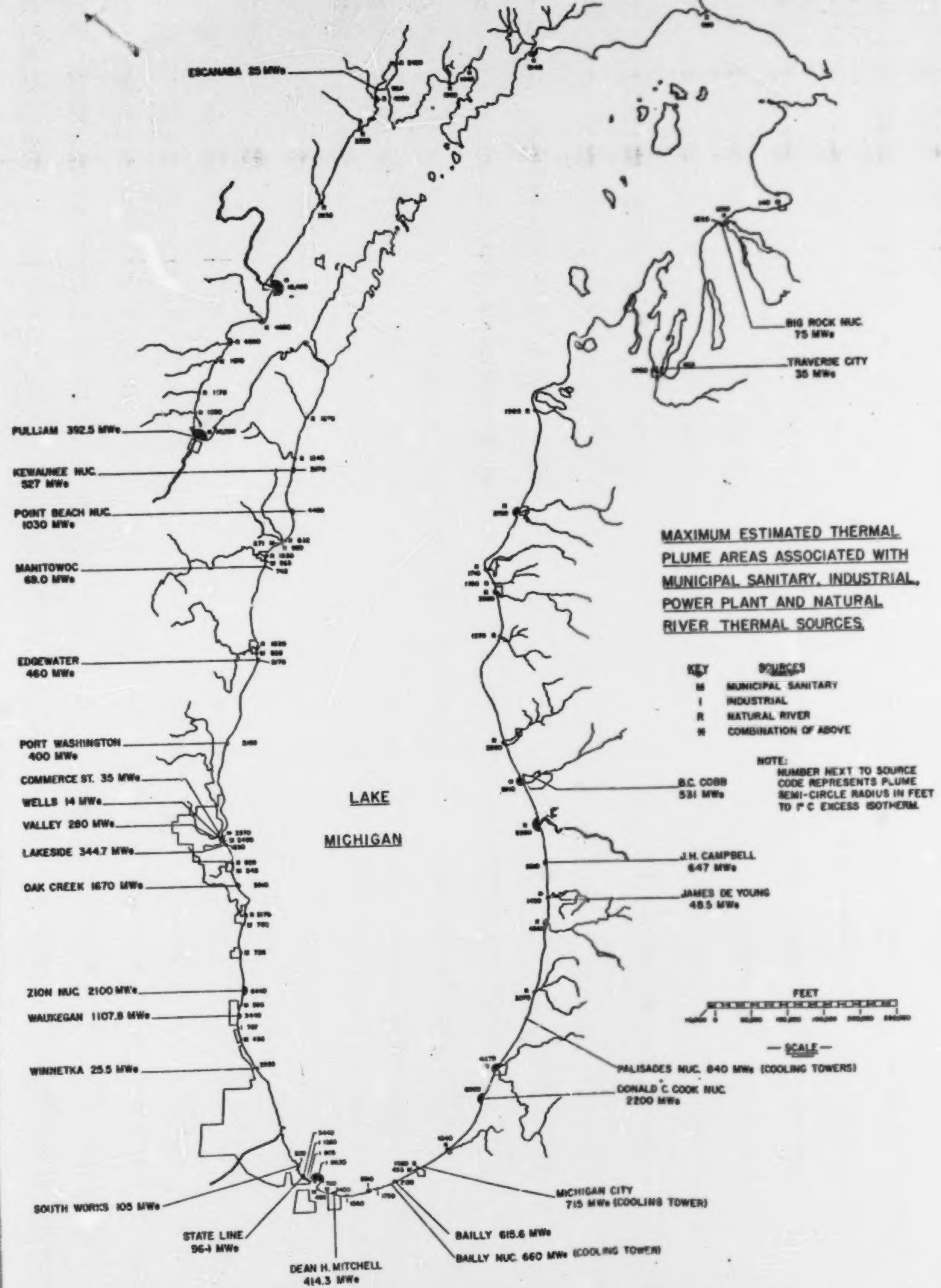


Fig. 3. Maximum Estimated Thermal-plume Areas Associated with Municipal, Sanitary, Industrial, Power-plant, and Natural River Thermal Sources.

over the period of record (1965-1969). These maximums occurred sometime in the summer when river-water temperatures are naturally higher than the lake temperatures. The river inputs would be relatively smaller on an average basis.

Thus Fig. 3 visually contrasts peak plume areas associated with natural and manmade thermal discharges to the lake. In some situations, municipal, industrial, and power-plant heated effluents are discharged to a river that is a tributary to Lake Michigan. Under these circumstances, it was not possible to separate the contributions of each source to the plume area shown in the figure. Each of these situations is marked with an asterisk. The power-plant sources have been singled out by name; other sources have been designated by the fact that they are municipal (M), industrial (I), natural (R), or combinations of these sources. The numbers refer to the radius of the semicircles, in feet, that have the same areas as the thermal plumes they represent.

1. Field Data

An observation of the sinking-plume phenomena at the Point Beach Plant was reported by Hoglund and Spigarelli.[59] Temperature recorders were placed on the bottom of Lake Michigan near the plant discharge. Analysis of the data revealed that the discharge water interacted with the lake bottom as long as the ambient lake temperature was 39.2°F or less. When the ambient lake temperature exceeded 39.2°F, there was little indication of temperature perturbations on the bottom as a result of the thermal discharge. The data are presented in terms of the percentage of the time the various recorders were influenced by the plume. The possible biological implications of this work are discussed later in this section.

Ten thermal plumes have been mapped at the Waukegan Plant by Industrial Bio-Test Laboratories over a period from February 21, 1970, to June 2, 1971.[66-68] The plume data were obtained by boat transverses, vertical profiles being taken at stationary boat locations. Data locations were determined using boat radar equipped with a variable-range finder. Wet- and dry-bulb air temperatures were acquired, along with ambient wind direction and speed. Power-plant factors such as plant electrical loading, condenser water flow, and intake and discharge temperatures were also obtained. The data were presented in graphical form generally with horizontal sections showing isotemperature contours. In most instances, vertical cross sections of the plume also showing isotherms were provided. The plumes were obtained on the following dates: February 21, 1971 (shows sinking-plume phenomena); April 23, 1970; May 19, 1970; May 27, 1970; August 24, 1970; September 30, 1970; October 21, 1970; November 11, 1970; February 16, 1971 (sinking plume); and June 2, 1971 (cooperative field day).

The Bio-Test authors have summarized their field investigations by indicating that the Waukegan plumes are quite variable in size, configuration, and general characteristics, and are most influenced by wind and wind-induced currents. They observed that the plumes appeared to respond quickly to wind-induced current movement and were principally directed in a downwind direction. They stated that the outer perimeters of the plumes were found difficult to locate, mainly because of the temperature variability of the ambient water. They stated further that the heated effluent affects the lake-bottom temperature only a short distance from the outfall, except when the wind blows parallel to the shore or slightly onshore, causing the plume to remain in shallow water close to the shore. Heated water was found to extend more than a mile downwind on such occasions with a strong along-shore breeze.

The heated-plume water was stated to rise quite rapidly after the initial momentum of the discharge velocity was reduced. When winter lake ambient temperatures were either at or near freezing, the plume was stated to sink to the lake bottom and to spread over the floor. It was found, however, that the plume mixed with the ambient water quite rapidly under these conditions.

Consumers Power Company has available two documents summarizing 1970 and 1971 in-house thermal-plume temperature surveys performed at various company plants throughout Michigan.[31,32] Of particular interest are those studies relating to plants on Lake Michigan. The 1970 field surveys consisted of making temperature measurements at various water depths throughout an established grid of marker buoys in the survey area. The temperatures acquired were plotted as a function of position for particular depth levels, and isotemperature contours were then drawn. Power-plant operating data in the form of plant electrical output, condenser cooling-water flows, and cooling-water intake and discharge temperatures were recorded. Ambient wind speed and direction, air temperature, and relative humidity were the atmospheric variables recorded.

Three temperature surveys were performed at the J. H. Campbell plant on July 10, August 26, and September 9, 1970. Only water surface temperatures were measured on these three field days. On September 9, vertical temperature measurements were additionally made at five stations. Two temperature surveys were performed at the B. C. Cobb plant, located on Muskegon Lake, which empties into Lake Michigan. The surveys were made on July 16 and July 17.

The 1971 field surveys were somewhat more extensive in that the surveys also included water chemical sampling and drift-bottle studies. The water sampling results were not included in the report. Three field studies were performed at the Big Rock Point Plant: June 30, July 1, and July 2, 1971. Six field studies were made at the J. H. Campbell Plant: June 17, June 18, July 7, July 8, August 3, and August 4, 1971. Five studies were made at the B. C. Cobb Plant: June 23, June 24, June 25, August 5, and August 6, 1971.

In a brief summary of these plume measurements, the report stated that the heated-plume water was buoyant and spread into relatively thin layers on the surface of the receiving waters. The extent of mixing with adjacent waters was stated not to be well defined; however, it appeared that maximum mixing occurred after the plume had cooled down to within 5.4°F of the ambient receiving water.

A compilation of 1971 field data gathered by Argonne National Laboratory relating to physical measurements of thermal discharges for several power plants sited on the lake have been reported by Frigo and Frye.[51] The field investigations basically consisted of temperature, water current, and meteorological measurements. Water temperatures were measured by boat using a submerged boom with probes attached at various depths.

Ambient water current and meteorological information consisting of wet- and dry-bulb air temperatures, and wind speed and direction were typically recorded for each plume investigation. Power-plant operating data were acquired from utility personnel. The report also describes plume measurements made using airborne infrared imagery techniques. A study of the sinking-plume phenomenon was also described.

Plume measurements were made at the Point Beach Plant during March and April (sinking-plume study), on May 20, June 25, and July 20; two plumes on July 21 and August 31; two plumes and an airborne infrared imagery study on September 1; two plumes on October 28; and a near-field jet study on November 3, 1971. Two plume measurements were made at the Waukegan Plant on June 2. This was part of a cooperative field effort and is described separately in this section. Plume data were also obtained at the State Line Plant on August 4 as part of another cooperative effort. Most of the data obtained at the various plant sites were reported in graphical form. The figures present horizontal and vertical plume sections with isotherms drawn on 1°C intervals. The authors indicated that the data would be used as input to analytical modeling efforts within their organization.

A joint field day was conducted at the Waukegan Plant on June 2, 1971, to compare, among other things, various plume measurement techniques.[52] The results showed rather remarkable agreement between plume isotherms measured by two different organizations using in situ measurements obtained from moving boats. An airborne infrared mapping of the plume was only in fair agreement with the other two after the infrared data were corrected to account for plume-measurement time differences.

Thermal-plume temperature studies (September 19 and October 28, 1970) were reported on for the Bailly Power Station.[91] The temperature measurements were made by taking surface and vertical temperature profiles at numerous offshore sampling positions in the lake. Meteorological parameters such as wind speed and direction, cloud cover, air temperature, and relative humidity were recorded in addition to the plant operating parameters of electrical output, cooling water flows, and cooling water intake and discharge temperatures. The data were presented in conventional isotherm plots, but for the surface isotherms only.

Scarpace and Green have reported on a series of studies using airborne infrared imagery techniques to map thermal plumes at the Point Beach and Edgewater Power Plants.[105] In this preliminary reporting they pointed out a rather interesting and apparently not uncommon plume phenomenon which is readily apparent in an infrared image of the Point Beach plume shown in Fig. 4. The discharge temperature during infrared mapping was stated to be 78.3°F; the intake on the ambient water temperature was 61.5°F. Thus the darker areas within the figure represent higher temperature conditions. The authors attribute the wavelike patterns to "thermal fronts" moving outward from the discharge since they have thermal pictures of the plume every 5 min and can therefore follow frontal motion.

The authors also noticed cyclic temperature oscillations at a fixed location within the Point Beach plume at a depth of 9 ft. Although it was not stated whether these in situ measurements were made concurrently with the infrared measurements, the authors believed that such bulk-temperature oscillations suggest that the thermal fronts are not just a surface phenomenon. Infrared techniques would measure only the temperature of the first tens of microns of the surface water.

In a more recent paper,[106] Scarpace and Green discuss additional infrared plume measurements made at the Point Beach Plant between September 14 and 17, 1971, and additionally speculate on plausible explanations for the presence of the thermal fronts. Apparently the fronts seem to be the strongest in very calm weather and are not evident during high-sea observations. The strength of the fronts seems to vary from day to day. Horizontal plume temperature gradients larger than 0.9°F/ft were said to be observed with frontal motion. It was also observed that secondary waves were superimposed on the thermal fronts. The secondary waves were discovered with near-infrared photographs; they were just barely visible with the infrared imagery. Explanations for the secondary waves were also discussed.

In summary, the authors felt that the presence of moving thermal fronts adds a significant dimension to the already complicated biological and physical aspects of heated discharges.

A comprehensive infrared study of three power-plant sites on Lake Michigan was reported on by Stewart, Brown, and Polcyn.[110] The broad purpose of the study was to conduct multispectral diurnal surveys of power-plant effluents into Lake Michigan and to investigate, where possible, the various effects and interactions between these plumes and the

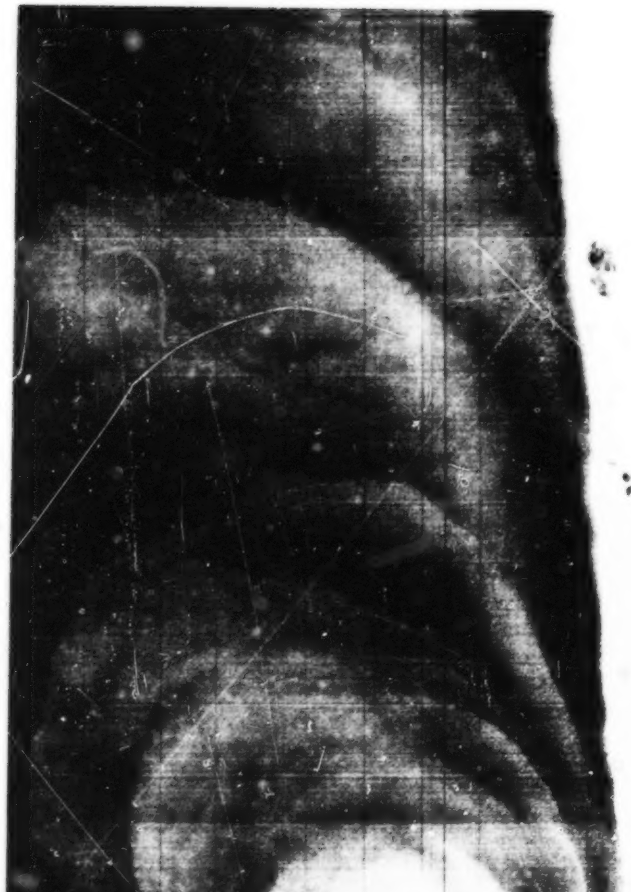


Fig. 4. Thermal Line-Scanner Image of Point Beach Power Plant Plume (Plane height 1600 ft; 5-milliradian detector)[105]

natural ecology of the lake. Specifically, the report furnished (a) plume imagery data, (b) an analysis of imagery gathered on growth and movement of the thermal bar, (c) a study of wind effects on plume distribution, and (d) a study of the relationship between the thermal bar, natural river outfalls, and power-plant discharges.

Infrared scans were made on the J. H. Campbell Plant on April 22, 23, and 30 and May 28, 1971. The data showed extreme plume variability, dependent on wind speed and direction and wind history. Complete plume reversals within a 2-hr period were noted; subtle changes were noticed in a span of 25 min.

The Michigan City Plant was studied on April 23, April 30, May 7, and May 28, 1971. The smallest plume occurred on the day of the strongest winds. A wave pattern in the April 23 data was noticed. (These "waves" looked much like the thermal fronts described by Ref. 106.)

The Bailly Plant was investigated on April 23, April 30, May 7, and May 28, 1971. The April 23 data shows some thermal-wave-pattern structure in the plume.

Some of the imagery data for the plants were presented in three unique forms as a result of computer analysis of the data. In one form the plumes were shown contoured into discrete temperature contour bands, the sum of these bands representing a mosaic for the entire plume. The second display form involved color-coded temperature contours. The third display form involved the use of computer symbol signatures combined with color overlays to denote the temperature contours. The data results were also tabulated to provide plume areas for a particular 1°F temperature interval.

A bibliography of thermal-plume field investigations conducted on large lakes was reported on by Tokar.[114] This report was a state-of-the-art survey, which attempted to identify existing thermal-plume field data that could be used to support or verify analytical plume-modeling efforts associated with heated-water discharges into the Great Lakes. The report is somewhat dated in that most of the reviewed plume data, with a few exceptions, were of a 1970 origin or earlier. Nevertheless, much of what the report concluded on the plume field investigations up to 1970 is perhaps appropriate even to this date.

The author concluded that the major difficulties associated with using existing field data for validating or improving analytical predictive methods are: (a) The transient nature of the plumes makes it difficult to obtain truly characteristic data by normal techniques. (b) Many partial investigations of thermal plumes are being performed by a number of groups, often at the same location. Dilution of effort appears to be common.

(c) Different mathematical models require different kinds of data, so that data that are sufficient for one study may not be sufficient for another.

The report also provided an inventory of all the major power plants sited on the Great Lakes and information indicating plant siting in terms of electrical output versus state and lake distribution.

2. Mathematical Modeling

In two reports, one by Asbury and Frigo[4] and the other by Frigo,[53] thermal-plume field data were used to develop and validate a simple phenomenological relationship for predicting the surface areas of thermal plumes in lakes. According to the authors, the relationship they obtained represents a useful rule of thumb for predicting surface areas of buoyant plumes from surface discharges. The actual relationship was presented as an eyeball data fit on log-log graph paper.

An analytical expression for the data of Asbury and Frigo was obtained by Elliott and Harkness[43] using a least-squares fit. Their relationship is

$$\frac{\theta}{\theta_o} = 1.0 - 0.456\left\{\frac{A}{Q\theta_o} \times 10^{-2}\right\}^{0.297},$$

where θ and θ_o are the plume excess temperatures at any point within the plume and at the immediate point of discharge, respectively, A is the total area, in square feet, of the plume up to the θ excess isotherm, and Q is the volumetric discharge rate, in cubic feet per second, of the cooling water.

In Ref. 53, Frigo correlated much of Argonne National Laboratory's 1971 plume field data, taken at various Lake Michigan-sited power plants, with the phenomenological model. All the new data fell within the data scatter envelope of the phenomenological relationship, and it was concluded that the validity of the relationship was further strengthened.

A state-of-the-art report concerning the mathematical modeling of thermal discharges into large lakes was reported on by Policastro and Tokar.[92] Sixteen analytical models were critically reviewed discussing individual model treatment of geometric, kinematic, hydrodynamic, and thermodynamic variables. The models reviewed did not represent all of those that could be used for lake applications. Therefore a bibliography of other models holding potential merit in this regard was also included. One of the models reviewed has been used to make plume temperature predictions for the Zion Station discharges into Lake Michigan. All the material in the report is highly technical, including its six pages of conclusions and observations.

A workbook containing computational procedures in the form of nomograms for estimating the temperature distribution and physical spread of heated discharges originating from submerged discharges has been authored by Shirazi and Davis.[108]

3. Hydraulic Modeling

Hydraulic-model studies of the proposed Zion Station Unit 1 discharge have been made by the Alden Laboratories.[26,78] The purpose of these studies was to determine the temperature-dilution patterns and effects of the condenser cooling-water discharge on Lake Michigan. The model was adjusted and operated to reproduce prototype conditions at the point of discharge. The test facility and test procedures were designed to simulate field conditions expected at both Zion discharge structures. The tests were conducted for a variety of conditions of lake depth and flow. The test results were presented in pictorial form showing water-temperature distributions in the vicinity of the discharge in plan and vertical views.

The analytical-plume-modeling efforts for the Zion Station are also given in Ref. 26. Together they form a complementary set of data and are discussed in relation to each other in testimony given at the Illinois Pollution Control Board Hearings on January 24, 1972, by D. W. Pritchard.[99] Dr. Pritchard pointed out that the analytical-modeling results overestimated plume lengths in relation to the hydraulic-modeling results for the higher excess isotherms. For lower excess temperatures (<9°F), the two forms of modeling were said to be in complete agreement. The plume areas predicted by the two modeling techniques show the analytical method to predict larger areas by a factor of 1.65.

Alden Laboratories have also performed hydraulic-modeling studies for the D. C. Cook Plant.[64] An undistorted model was used with a 1/75-scale ratio to model the discharge region as accurately as possible. The experimental features of the tank limited the hydraulic-modeling results to the equivalent of 4000 ft in either direction along the shore and out to 4000-ft offshore. Preliminary trials indicated that the 3°F excess isotherm (used in water-quality regulations) could not be closed within the tank, so analytical procedures were used to complete the task. Most of the information gathered thus far was performed on the basis of the discharge structures using three discharge slots. Tests are currently being performed on the basis of using two slots per discharge.

4. Effects on Shoreline Ice

The main source of information on shore ice development and destruction, and on the potential effects of thermal discharges on this ice, is work by Ayers.[8] During the winters of 1969-70 and 1970-71, aerial photographic ice-reconnaissance surveys of the entire shoreline of

Lake Michigan were performed to observe and photograph the alongshore ice and open-water areas in the vicinity of nuclear and fossil-fuel power plants. On-foot photographic records of the shore ice conditions were obtained at the Cook Plant site and at the sites of existing thermal discharges.

As a result of these activities, Ayers has derived abundant evidence that the shore ice along the Lake Michigan shore has a complex structure called "the storm icefoot, lagoon, and outer barrier." The method of formation and details of this compound structure are discussed in Ref. 8.

Ayers et al. state that evidence from two winters of ice studies "does not show that discharges of waste heat cause extensive melting of shore ice with the resulting exposure of the beaches to wave erosion. Instead, the data show that the usual outfall structure, a sheet-pile flume leading out into the water, will have shore ice continuing up to the very sides of the flume ... (However) At Campbell there has been, both winters, a considerable area of shore ice melted, but beach erosion has not been evident."[8]

Using an analysis of lake currents and wind-direction patterns, Ayers et al. concluded that during two-thirds of the winter the Cook Plant plume will not have significant contact with the shore ice and the natural processes of ice-building and ice-destruction will be in control. "The Cook Plant thermal plume appears, at this time, to be an ice-destructive force potentially operative about a third of the time in winter. During this time it will be a destructive force wandering randomly along the shore, staying in contact with the shore ice for very limited periods at any local point. Since its ice destructive force will always be preceded and followed by the natural forces of ice-building and ice-destruction, we conclude that the effect of the Cook plume on local shore ice will be only a limited diminution in the amount of ice present."[8]

B. Biological Characteristics

Coutant[36] summarized the concern about thermal discharges as follows:

> "We visualize the power plant as a large artificial predator acting on these populations. Our opinion has been molded by laboratory experiments which have shown that thermal shocks may lead to death or induce secondary effects that ultimately affect survival of the organism or its population. We may fail to realize, however, that these devastating results are not obligatory in the entrainment process. Rather, they occur only as a result of specific combinations of temperature and duration of exposure."

This section describes studies performed and testimonies presented that are relevant to these effects of "temperature and duration of exposure" on aquatic organisms. Many of these organisms are of immediate importance to man through commercial fisheries, sport fisheries, or biological nuisances.[119] Others are important as food-chain contributors to those species of more direct interest. Still others are important components of the entire ecosystem, without which other processes in the lake could not proceed.[119]

A division was made in this report between thermal-plume effects and intake and discharge effects. Problems with fish kills on intake screens and mechanical damage due to pumping were easily relegated to the section on intakes and discharges. However, some of the temperature-related effects, such as periphyton growth and fish behavior, were not clearly separable into the specific sections. Thus, a somewhat arbitrary decision was made to describe those studies that were performed primarily in the intake or discharge in the section on Intake and Discharge Effects. Those studies that included lake measurements as well as intake and discharge measurements are reported here.

1. Waukegan Power Plant

A number of studies of the biological effects of thermal discharges have been undertaken by the Bio-Test Laboratories for Commonwealth Edison. The studies use the heated discharge of the Waukegan power plant.

Following preliminary studies in 1968, reported by Beer and Pipes,[13] fish collections were made near the Waukegan and Zion areas from March through October 1970. Thirteen species were taken in the Waukegan area and 17 in the Zion area.[73] The most dominant fish were alewife, smelt, spottail shiner, chub, and yellow perch. The data indicated that alewives seemed to prefer the warm discharge water throughout the test period; the coho salmon seemed to prefer it only during the spring.

During 1971, alewives were again the most abundant in the sampling area, with very large concentrations in the discharge during August and September. A heavy concentration of adult spottail shiners was observed in the Waukegan discharge in June, but no young-of-the-year were taken in subsequent samples.

Fish that were present throughout the year in both the Waukegan intake and discharge canals were carp, goldfish, and white suckers. Sport fish taken during early spring and late fall included brown trout, rainbow trout, and coho salmon. They were found mainly in the intake canal, though a few were captured in the discharge.[72]

Phytoplankton samples taken in May to September 1970 indicated no significant differences in total population densities between the intake and discharge canals. Offshore densities were somewhat lower than the canal densities. Diversity and evenness indexes showed little difference among populations in the intake, discharge, and offshore during the sampling period.[28] These results were essentially confirmed during the 1971 studies.[72]

Monthly sampling of zooplankton in and out of the Waukegan plume was carried out from June through October 1970. Generally, there were more organisms inside than outside the plume.

Ayers[6] conducted studies at the Waukegan Station on June 30, 1969 (intake temperature, 55°F; outfall temperature, 61.9°F), and found an apparent phytoplankton kill of 10%. There was no evidence of heat-stimulated recovery in the near region of the plume. The population-density ratio, with respect to a station 2000 ft from the outfall, was 0.6:1.[6]

The zooplankton numbers indicated similar trends with the population density reduced 15% at the outfall and a ratio (plume/outfall) of 0.2:1 at 2000 ft.[6]

"In summary, the biological data show kill-off of both phytoplankton and zooplankton in passage through the plant. In both types of plankton there appears to have been continuation of die-off between the outfall and the nearby portion of the plume. Benthos results showed nothing attributable to the plant except bottom scour due to currents in the intake and outfall."[6]

2. Point Beach Power Plant

The plankton, periphyton, and benthos communities of inshore waters were sampled near the Point Beach Nuclear Plant by Argonne National Laboratory, during 1971, to determine the biological effects of the thermal discharge.[109] With respect to phytoplankton, it was concluded from vertical tows for plankton that no significant differences existed between plume and nonplume water in terms of plankton biomass. However, fluorometric analysis of phytoplankton samples showed considerable variation in chlorophyl a concentration (proportional to phytoplankton productivity) at the sampling stations. Initially (nearest the discharge), there seemed to be an inhibition in chlorophyl a. Approximately 1400 ft from the discharge an increase had occurred, and at greater distances the levels decreased to near ambient concentrations. A significant increase in chlorophyl a concentration was observed in the plume in July, when an upwelling resulted in elevated nutrient concentration.

With respect to periphyton, its growth was significantly greater at the three stations nearest the discharge. Growth at all other stations was similar to that at the control areas. Periphyton productivity, as measured by ^{14}C uptake, was significantly higher at a station 5000 ft from the discharge than at the control station and at a station nearer the discharge. The elevated temperature near the discharge apparently did not stimulate periphyton production during the period of the study.

Fish were routinely collected by Argonne National Laboratory[102] from several locations, including the discharge canal, the beach zone near the discharge, and a control beach zone approximately 2 miles north of the Point Beach plant. Hand seining was used in the shallow beach zones, and scuba divers speared large fish in the discharge canal. This sampling disclosed that during the summer months of May through July, alewives were the most abundant fish in the discharge canal and the beach zone. Dense schools were observed in the discharge canal and often out into the lake as far as 150 yards from the discharge. Carp were the most commonly observed fish, both in the discharge and beach zones. Schools of 10-30 fish swam in and out of the discharge canal along the sides and bottom through temperature gradients of up to 18°F. Suckers were observed each time divers entered the discharge (June-September). Smallmouth bass of various sizes were observed only in the discharge. Trout and salmon were not observed in the discharge channel during the higher-temperature periods (>72°F). Trout and salmon also frequented the near-field plume region as evidenced by good catches made by boat fishermen.

The spatial distribution of fish in and around a thermal plume was observed by Argonne National Laboratory during tests to examine the feasibility of acoustic fish-locating equipment. On October 28, 1971, simultaneous echo-sounding and temperature measurements were made as a boat traversed through the Point Beach Nuclear Plant thermal plume. Observations were made in daylight and after dark. The major difference observed between the day and night runs was the presence of a large number of schools of fish during the day and the complete absence of schools during the night. The number of individual fish observed at night is almost seven times greater than during the day. In general, during both the day and night series, the majority of fish (species unknown) were in water less than 55°F, and at no time were fish detected in plume water warmer than 59°F. Many fish, however, have been observed in the discharge canal in much higher temperatures.[103]

An interesting study of the effect of thermal discharges on the swimming patterns of coho salmon past the Point Beach Nuclear Plant has been released by The University of Wisconsin - Madison.[57] The fish were tracked by underwater telemetry equipment and a special temperature-sensitive ultrasonic transmitter attached externally to the fish. All fish tracked in 1971 were adult coho salmon captured at Algoma, Wisconsin. The fish were displaced 23 miles southward and released for tracking at a point approximately 0.9 mile southeast of the Point Beach water-intake structure.

Preliminary analysis of the 1971 tracking data indicates that three general patterns of movement were followed by the fish tracked in the Point Beach area: 1) Five fish closely followed the shore line and definitely did encounter the plume; 2) two fish swam approximately 0.3-0.6 mile offshore and may or may not have come into contact with the plume; and 3) four fish definitely did not encounter the plume.

Of the five fish that definitely contacted the thermal plume, two made a course change of about 90° at a point considered to be the location of the plume interface and subsequently swam approximately parallel to the interface. At the location of course change of these fish, the temperature increase across the plume interface was from 52 to 59°F in the first case, and from 55 to 61°F in the second. A third fish twice encountered the plume edge very near the hot-water-discharge structure, and upon each contact changed swimming direction by 180°. The temperature rise across the plume interface in this area was from 59 to 70°F. The fish was swimming northward at 1.6 ft per second. Immediately before first contacting the plume, his speed increased to 2.5 fps. After first contact with the plume, the fish changed direction and swam south, approximately 0.1 mile, at 0.8 fps. After turning northward again, he was swimming at 0.7 fps while approaching the plume for a second time. After the second contact, the fish swam 0.75 mile southward at 2 fps before turning north and approaching the discharge area a third time. The transmitter signal was then lost after the fish had been tracked to within 0.2 mile of the discharge structure. The tracking signal was also lost from two other fish which had entered the plume area before sufficient data on their behavior at the plume interface could be obtained.

Of the other fish that encountered the plume, all four exhibited a marked increase in swimming speed during the track segment immediately preceding contact with the plume. Three of these fish were lost in the plume due to transmitter failure, but the fourth was tracked through the plume. While passing through the plume, this fish decreased its swimming speed slightly from 2.3 to 2 fps. Two of the fish that were among those lost in the plume due to transmitter failure were later captured in their home stream area (Algoma, Wis.) by sport fishermen.

The effect upon fish resulting from power-plant shutdowns during emergency or normal situations were referred to briefly in Ref. 129. It was stated that it was significant to note that operating experience for the first six months at the Point Beach Station showed that with 20 shutdowns, occurring primarily in the winter months, no fish are known to have been killed and no other adverse effects were observed.

3. Blount Street Plant (Lake Monona)

A study to assess distributional responses of fishes to operation of a power plant with once-through cooling on Lake Monona was reported by

Neill and Magnuson.[80] Integration of field and laboratory results suggested that fishes were distributed within the outfall area according to their different temperature preferences. Preferred temperatures of six Lake Monona fishes were measured by allowing each of several specimens to behaviorally regulate the temperature of its tank. The midpoint of the preferred (laboratory-determined) temperature range agreed well with the median body temperature of the fish as measured in the outfall area during afternoon tests. For example, carp, 89.2 (laboratory)/87.1°F (field); blue gill, 86.5/84.9°F; large mouth bass, 84.4/85.5°F; black crappie, 82.9/82.9°F; rock bass, 81.1/81.5°F; and yellow perch, 74.1/80.8°F. (For yellow perch, temperatures below 79.7°F were not available in the outfall area.)

Temperature was a major factor governing fish distribution in that fish tended to be most abundant in that part of the habitat having temperatures within the species-preferred range of temperature as determined in the laboratory. Disparate distribution of some specific fish species of different size resulted from the influence of factors other than size-related differences in preferred temperature. For example, spatial segregation between young and adults of two species, carp and yellow bass, probably did not reflect size differences in preferred temperature. Adult carp were concentrated in the outfall area during summer, but the young carp were not, even though thermal regulatory behavior of young carp indicated that they preferred temperatures between 86 and 92.3°F, temperatures available only in the outfall area. Young yellow bass avoided the outfall area; larger yellow bass were relatively abundant there and were particularly concentrated near the jets. Yet, large yellow bass stayed near the bottom in water not much warmer than the reference areas where the young lived, indicating that temperature alone was not the dominant factor. Water-velocity effects were offered as one explanation for the above-mentioned behavior. Explanations of this behavior were not offered in the report.[80]

Laboratory experiments[80] with bluegills and yellow perch confirmed that fish may be attracted to food-rich environments, but suggested that the attraction to food does not override the behavioral thermal regulation. Provided an environment with the preferred temperature is available, the fraction of time spent in a food-rich environment is likely to decrease abruptly as the temperature diverges from the preferred. Fishes may, however, briefly foray from an environment offering the preferred temperature, but not food, into cooler or warmer (even lethally warm) water where food is available.

4. Michigan City Station

Biological data were obtained from the intake, outfall, and stations 400 and 1000 ft from the outfall, at the Michigan City Station on June 28, 1969.[6] The temperatures were: intake, 64°F; outfall, 77.4°F. The data indicated some kill-off of phytoplankters because the outfall population density was 14% less than that of the intake. Phytoplankton densities in the plume were larger than those in the outfall. The ratio was 2.45:1 at 400 ft and 1.34:1 at 1000 ft. Some of the increase was associated with the blue-green algae, Oscillatoria, and the yellow-brown alga Dinobryon, but the investigators could not tell if it was due to plant heat or to foreign water masses drifting in from the southwest.[6]

The zooplankton showed a decrease from intake to discharge of 2.9:1, and many dead or broken organisms were observed in the outfall sample. Zooplankton densities in the plume, relative to the outfall, varied from 5.3:1 to 0.2:1. As in the phytoplankton data, Ayers et al. were unsure whether drifting water masses affected the data.[6]

The waste heat from the Michigan City Generating Station did not appear to affect the benthic organisms.[6]

Table 4 summarizes direct measurements of the time required for a plastic bag, nearly filled with water, to travel from the mouth of the plant outfall to a point where ambient lake temperature was reached.[5] The short duration of bag drifts was unexpected. Ayers et al. indicate that, even in larger plumes, the duration of the greater than ambient temperatures is probably too brief to trigger excess algae blooms.[5]

5. Bailly Plant

Field data were obtained on two days during September and October 1970 at the Bailly Plant, located between Michigan City and Gary, Indiana. The purpose was to compare samples of the pertinent biological parameters obtained from the plume area and the adjacent ambient waters. A summary of the results[91] indicated higher concentrations of diatoms, dinoflagellates, and blue-green algae in samples taken from the warm water. However, concentrations of golden-brown algae (other than diatoms) and green algae were similar for samples both inside and outside the plume. Concentrations of green algae increased with decreasing distance from Burns Ditch. The growth was higher near shore than 4000 ft offshore.[91]

The periphyton showed greater concentrations of Cladophora glomerata both within the thermal plume and in adjacent areas than in areas along the southwest shore of the lake.[91] Zooplankton were three to four times more abundant within the thermal plume than outside it. In general, most forms found in the plume are characteristic of eutrophic conditions. The most abundant organism was the cladoceran, Daphnia retrocurva, followed by the copepod, Eurytemora affinis. Individuals of these species found within the plume were infested with fungus, whereas those collected outside did not exhibit any fungus.[91]

A large concentration of yellow perch were found in the plume at the time of sampling. The intake/discharge temperatures were 66/81°F

Table 4

Measurement of Residence Time in Thermal Plume

Place and Date	Load, MWe; Flow, gpm	Cooling Water ΔT, °F	Drift Time
Bailly 6/20/70	522.5; 150,000	12.6	30 min 28 min
Bailly 10/17/70	153.6; 150,000	4.	1 hr, 22 min
Michigan City 10/17/70	88; 70,000	10.8	1 hr, 04 min

on September 19 and 52.3/66.2°F on October 28, 1970. It was speculated the fish may have been attracted by the greater abundance of zooplankton in the region of the thermal plume.

6. J. H. Campbell Plant

A biological survey in the vicinity of the J. H. Campbell Plant was performed by the Michigan Water Resources Commission[116] during August 11-13, 1970. The plant was operating with an intake temperature of 63°F and a discharge temperature of 77°F. Bottom trawling for fish revealed no consistent differences between plume and nonplume areas. Most of the fish collected were young-of-the-year smelt. Yellow perch were next in abundance.

Large amounts of filamentous green algae, Cladophora, were collected in the trawl through the plume area. The origin of the algae was unknown.[116]

Plankton algae samples exhibited no gross numerical differences or changes in community structure between the discharge and ambient waters.[116]

Results from the benthic sampling indicated a statistically significant increase in number of species found near the discharge canal. Although there was a slight increase in total population near the discharge area, the population samples were not significantly different from the control points. It was speculated that the use of nutrient-laden water from the Pigeon River, for cooling, may have caused the increase in species.[116]

It was concluded[116] that the increased benthic productivity in the plant's outfall was the only adverse effect that could be attributed to the warm-water discharge.

7. Miscellaneous Studies

Several papers have been published during the last two years that provide laboratory temperature-tolerance data for several Lake Michigan fish. Edsall *et al*.[41] tested juvenile and young adult bloaters for tolerance to high temperatures. The "ultimate" upper lethal temperature (the lethal temperature that cannot be increased by increasing the acclimation temperature) for the juvenile bloaters was 80.1°F, slightly higher than that for the young adult bloaters. The thermal tolerance of juvenile bloaters was slightly less than that of brook trout, but higher than that of other Salmonidae.

Brungs[17] reported the exposure of fathead minnows to elevated water temperatures of 78.8-93.2°F. He found that reproduction was more sensitive than survival, growth, or egg hatchability in assessing the effect of temperature The number of eggs produced/female, the number of eggs/spawning, and the number of spawnings/female were gradually reduced at successive temperatures above 74.3°F. No spawning or mortality occurred at 89.6°F which was the lowest temperature where growth was apparently reduced.

McCormick _et_ _al_.[82] studied the thermal requirements of cisco larvae by determining growth rates, mortality, and net biomass gain as a function of temperature. Temperatures between 55.4 and 64.4°F were recommended as most suitable for sustained production of larval cisco. The 24-hr median lethal temperature for ciscos acclimated to 37.4°F was 67.6°F.

The avoidance mechanism, or selection of preferred temperatures, as described above, was also illustrated in an experiment described by Raney[104] during testimony before the Michigan Water Resources Commission. He cited one test in which six alewives, acclimated at 77°F, chose 82°F water when given the choice between 74 and 82°F, and chose 80°F water when the alternative was 86°F. In a similar test, six other alewives, acclimated at 77°F, chose 83°F water over 75°F water and then chose 80°F water when 86°F was the alternative. He said, "This illustrates the expected reaction of a species, such as an alewife, if and when it comes close to a heated plume."

Testimony by Lauer[79] before the Michigan Water Resources Commission included data related to several aspects of thermal effects on lake biota. Concerning phytoplankton, experiments have shown the diatom, _Asterionella_ _formosa_, was capable of one division per day at 50°F and two divisions per day at 68°F. Under optimum growing conditions, some algae are capable of three generations per day. Most algae species studied have a lethal temperature in the range of 91-113°F, the majority being near 111°F. Diatoms that require cooler temperature (stenotherms) are generally most sensitive to temperature change and can withstand an 18°F temperature change.

Lauer[79] stated that at none of 10 operating power plants had he observed a discernible shift in species diversity resulting from the water temperature increase. He attributed this to the relatively short exposure time of the organisms to the heated water.

The doubling time of zooplankton crustaceans such as copepods and cladocera is very dependent on temperature.[79] Doubling times of 0.2-2 days have been observed for these organisms at temperatures of approximately 77°F. The population turnover rate (100% replacement by a new crop) may be as rapid as 4 days or less at 77°F, and up to 22 days or longer when temperatures are lower. Twenty-five of a 28% average loss per day at summer temperatures has been observed to be due to predation. The maximum temperature tolerance of the majority of zooplankton species studied range between 86 and 95°F.

Using lake-bottom temperatures measured continuously during March and April 1971 during a study of the sinking-plume phenomenon at the Point Beach Plant, Hoglund and Spigarelli[59] used the data of Colby and Brooke[25] to predict the hatching time of lake herring eggs subjected to the observed temperatures during their incubation period. For the conditions studied (2000 ft from discharge, 21 ft deep), the calculations predicted the lake herring emergence would be advanced about 7 days as a result of exposure to the sinking plume.

A rather significant development related to the problem of power-plant design and site selection has been reported by Coutant.[36] He described steps being taken to develop quantitative mathematical predictability of detrimental biological effects of thermal discharges. For instance, a "survival nomogram" (a graphical representation of lethal temperatures versus time, with acclimation-temperature parameters) may be prepared for many aquatic species for which sufficient data may be available. Then, with the aid of a time-at-temperature graph, developed by analyzing the velocities and temperatures an organism will experience while passing through the plant and plume, one may determine if lethal conditions will be experienced by the organism being studied. If this type of analysis is performed during the design stage of the plant, then engineering changes that affect the temperatures or velocities may be incorporated to minimize the problem. For those who prefer the mathematical approach, these data are easily converted to a set of regression equations.

With the acquisition of sufficient data related to sublethal effects, such as equilibrium loss and increased susceptibility to predation, the method described above may be used to estimate the probability of these effects or to design the plant to minimize them.

If accepted, this approach clearly defines the type of laboratory and field data that must be acquired to make full use of its utility.

IV. INTAKE AND DISCHARGE EFFECTS

A. Inventory of Designs

Summary operational data for most power plants on or in the proximity to Lake Michigan can be found in either the Department of the Army, Corps of Engineers, "Application for Permit to Discharge or Work in Navigable Waters and their Tributaries-Eng Form 4345," or in the Federal Power Commission's Statement Form, "Steam-Electric Plant Air and Water Quality Control Data for the Year ended December 31, 1971, FPC Form 67." Both of these forms contain fairly comprehensive submissions from the various utilities concerning cooling-water operational data for their various power plants.

The Army Corps permit application must be completed by any person or entity seeking to directly or indirectly discharge or deposit refuse matter into navigable waters or their tributaries. The policy has been to interpret the discharge of waste heat as refuse, and, therefore, utilization of once-through condenser cooling by electrical power-generating facilities requires the submission of a corps application.

The FPC form contains information on air as well as water quality-control data. The form must be completed for every steam-electric station having a generating capacity of 25 MWe or greater that belongs to an electrical utility system with a capacity equal to or greater than 150 MWe. It is also required if the 25-MWe plant lies within a National Air Quality Control Region, regardless of whether the facility is part of a larger system.

Space limitations preclude the incorporation of the complete Corps and FPC forms for all the major steam-electric power plants sited on or next to the Lake. Only selected facts from these documents have been included here to give the reader a perspective for the relative sizes between the various individual operating plants and their respective cooling-water requirements. Table 5 presents these selected data for those plants with a 75-MWe nameplate rating or greater. The rationale for selecting the 75-MWe rating is suggested by EPA's specific cognizance of heated discharges greater than 0.5×10^9 Btu/hr. A 0.5×10^9-Btu/hr thermal-discharge rate roughly corresponds to the waste-heat discharge from a 33% efficient, 75-MWe nuclear plant. Table 5 is not inclusive for yet another reason. Heated effluents are being discharged into the Lake, either directly or indirectly, by several industrial facilities such as U.S. Steel South Works in Chicago, Inland Steel, Youngstown Steel, American Oil, Union Carbide, and others in the industrial sectors along the Indiana shoreline.

Table 5

Power Plant Operating Information

Plant Name	Pulliam	Kewaunee	Pt. Beach	Port Washington
Town	Green Bay	"	Two Creeks	"
Nameplate Rating (MWe)	392.5	540 (PWR)	1048 (PWR/s)	400
*Daily Average Generation (MWe)	250			258.2
Plant Factor (%)	64			65
Initial Year of Plant Operation	1927	1972	1970;1972	1935
Overall Plant Cost ($\$x10^{-6}$)	48.9	137	160	48.2
Cooling System Cost ($\$x10^{-6}$)	2.37	3.53		0.697
Cooling System O & M Expenses	69			91
Estimated Plant Thermal Efficiency (%)	31	33	33	31
Maximum Cooling Water Flow (GPMx10^{-3})	375	413	700	549
**Calculated Max. Thermal Discharge (Btu/hr x 10^{-9})	2.5	4.1	6.8	2.5
***Calculated Max. Temperature Rise (^{O}F)	13.3	20	19.3	9.1
Location of Discharge	Shoreline	Shoreline	Offshore	Shoreline
Location of Intake	Shoreline	Offshore	Offshore	Shoreline

*From Army Corps form dated 1971

**Calculated assuming 12% Fossil Plant Stack Losses and Cited Estimate of Plant Thermal Efficiency

***Calculated from Thermal Discharge Rate and Cooling Water Flow Rate

Table 5 (Continued)

Plant Name	Edgewater	Lakeside	Valley	Oak Creek
Town	Sheboygan	St. Francis	Milwaukee	"
Nameplate Rating (MWe)	477	311	280	1670
*Daily Average Generation (MWe)	241	100	181	980
Plant Factor (%)	51	32	65	59
Initial Year of Plant Operation	1931	1920	1968	1953
Overall Plant Cost ($\$x10^{6}$)	54.5		41.1	202
Cooling System Cost ($\$x10^{6}$)	0.300	0.557	0.857	3.45
Cooling System O & M Expenses	14	84	27	281
Estimated Plant Thermal Efficiency (%)	28	30	38	37
Maximum Cooling Water Flow (GPMx10^{-3})	236	479	112	1228
**Calculated Max. Thermal Discharge (Btu/hr x 10^{-9})	3.5	2.0	1.3	7.8
***Calculated Max. Temperature Rise (^{O}F)	29.7	8.3	23.2	12.7
Location of Discharge	Shoreline	Shoreline	Menomonee	Shoreline
Location of Intake	Offshore	Shoreline	River	Shoreline

*From Army Corps form dated 1971

**Calculated assuming 12% Fossil Plant Stack Losses and Cited Estimate of Plant Thermal Efficiency

***Calculated from Thermal Discharge Rate and Cooling Water Flow Rate

Table 5 (Continued)

Plant Name	Zion	Waukegan	State Line	D.H. Mitchell
Town	"	"	Hammond	Gary
Nameplate Rating (MWe)	2200 (PWR/s)	1043	972	414
*Daily Average Generation (MWe)		588	585	504 (suspect)
Plant Factor (%)		56	60	120
Initial Year of Plant Operation	1972;1973	1923	1929	1956
Overall Plant Cost ($\$x10^{-6}$)	424	137	125	59.5
Cooling System Cost ($\$x10^{-6}$)		4.86	2.25	2.47
Cooling System O & M Expenses		61	76	2
Estimated Plant Thermal Efficiency (%)	33	33	33	35
Maximum Cooling Water Flow (GPMx10^{-3})	1500	873	829	423
**Calculated Max. Thermal Discharge (Btu/hr x 10^{-9})	15	5.9	5.5	2.1
***Calculated Max. Temperature Rise (^{o}F)	20	13.5	13.3	9.9
Location of Discharge	Offshore	Shoreline	Shoreline	Shoreline
Location of Intake	Offshore	Shoreline	Shoreline	Shoreline

*From Army Corps form dated 1971

**Calculated assuming 12% Fossil Plant Stack Losses and Cited Estimate of Plant Thermal Efficiency

***Calculated from Thermal Discharge Rate and Cooling Water Flow Rate

Table 5 (Continued)

	Bailly	Michigan City	D.C. Cook	Palisades
Plant Name	Chesterton	"	Bridgman	Covert
Town Nameplate Rating (MWe)	616	211	2200 (PWR/s)	700 (PWR)
*Daily Average Generation (MWe)	591	206		
Plant Factor (%)	96	94		
Initial Year of Plant Operation	1962	1930	1973;1974	1971
Overall Plant Cost ($\$\text{x}10^{-6}$)	89.0	29.1	485	171
Cooling System Cost ($\$\text{x}10^{-6}$)	3.92	0.799		
Cooling System O & M Expenses	1	1		
Estimated Plant Thermal Efficiency (%)	34	27	33	33
Maximum Cooling Water Flow ($\text{GPMx}10^{-3}$)	337	246	710;935	405
**Calcuiated Max. Thermal Discharge (Btu/hr x 10^{-9})	3.3	1.6	7.6;7.6	5.0
***Calculated Max. Temperature Rise (^{o}F)	19.6	13.0	21.4;16.2	25
Location of Discharge	Offshore	Shoreline	Offshore	Offshore
Location of Intake	Offshore	Shoreline	Offshore	Offshore

*From Army Corps form dated 1971

**Calculated assuming 12% Fossil Plant Stack Losses and Cited Estimate of Plant Thermal Efficiency

***Calculated from Thermal Discharge Rate and Cooling Water Flow Rate

Table 5 (Continued)

Plant Name	J.H. Campbell	B.C. Cobb	Big Rock
Town	West Olive	Muskegon	Charlevoix
Nameplate Rating (MWe)	650	511	75 (PWR)
*Daily Average Generation (MWe)	495	336	53
Plant Factor (%)	76	66	71
Initial Year of Plant Operation	1962	1948	1962
Overall Plant Cost ($$\times10^6$)	89.1	63.7	14.6
Cooling System Cost ($$\times10^6$)			
Cooling System O & M Expenses		2.5	21
Estimated Plant Thermal Efficiency (%)	38	32	31
Maximum Cooling Water Flow (GPM$\times10^{-3}$)	300	405	48
**Calculated Max. Thermal Discharge (Btu/hr x 10^{-9})	2.9	3.0	0.57
***Calculated Max. Temperature Rise (^{o}F)	19.3	14.8	23.7
Location of Discharge	Onshore	Muskegon	Offshore
Location of Intake	Pigeon Lake	River & Lake	Offshore

*From Army Corps form dated 1971

**Calculated assuming 12% Fossil Plant Stack Losses and Cited Estimate of Plant Thermal Efficiency

***Calculated from Thermal Discharge Rate and Cooling Water Flow Rate

To better understand the mechanisms of power-plant cooling, the current design features of the cooling systems for five major nuclear power plants sited on Lake Michigan will now be described.

1. Kewaunee Plant Cooling System

The condenser cooling-water system for the Kewaunee Plant is shown schematically in Fig. 5. Briefly, the cooling water is withdrawn from the lake at three intake ports located about 14 ft below the lake surface. Steel trash grills with 1-ft-square openings are installed above the intake openings to prevent large debris from entering the system. In addition, an air-bubble screen around the periphery of the intake structure discourages possible fish penetrations. Most of the intake structure and the entire 10-ft-dia intake pipe leading from the structure to the plant is buried below the bottom of the lake. The cooling water is drawn through the intake ports, in a downward direction, at about 0.9 fps. It flows by action of gravity through the 10-ft-ID intake pipe and empties into the forebay of the screenhouse. The water velocity in the intake pipe at full flow is about 11 fps. The screenhouse forebay acts as a stilling basin to reduce the water velocity before the water passes through a bar or trash grill (size unknown) and the traveling or rotating screens.

Each traveling screen has a 3/8-in. mesh. Each screen is a continuous belt constructed of screening panels with a shelf at the lower edge of each panel. The screen is rotated upward in a plane normal to the waterflow direction. Any debris larger than about 3/8 in. is thus "caught" by the screen, and as the screen moves upward out of the flowing water, the debris falls off into the shelves. These shelves are backwashed automatically, the debris being sluiced to a strainer casket, where it is collected and eventually removed for onsite burial. A hypochlorinating system is provided to inject sodium hypochlorite, if necessary, into the inlet of the traveling screens to prevent the buildup of bacterial slime on the condenser tubes.

After the water passes through the screens, it is still within a large basin, which helps to distribute the waterflow evenly to the circulating-water-pump intakes located at the bottom of the basin. The circulating-water pumps then deliver this water to the condenser. While the circulating pumps are operational, the water surface level in the basin is liable to be many feet below the lake surface level, which allows lake water to be drawn into the intake system by gravitational flow.

As the cooling water flows through the condenser it picks up heat. The heated cooling water is returned to the lake by means of a discharge basin located at the shoreline. The basin is approximately 40 ft wide at the shoreline discharge point. During the winter, to control the formation of ice in the system, the circulation flow will be reduced to 287,000 gpm with a corresponding rise in temperature of the cooling water of about 29°F.

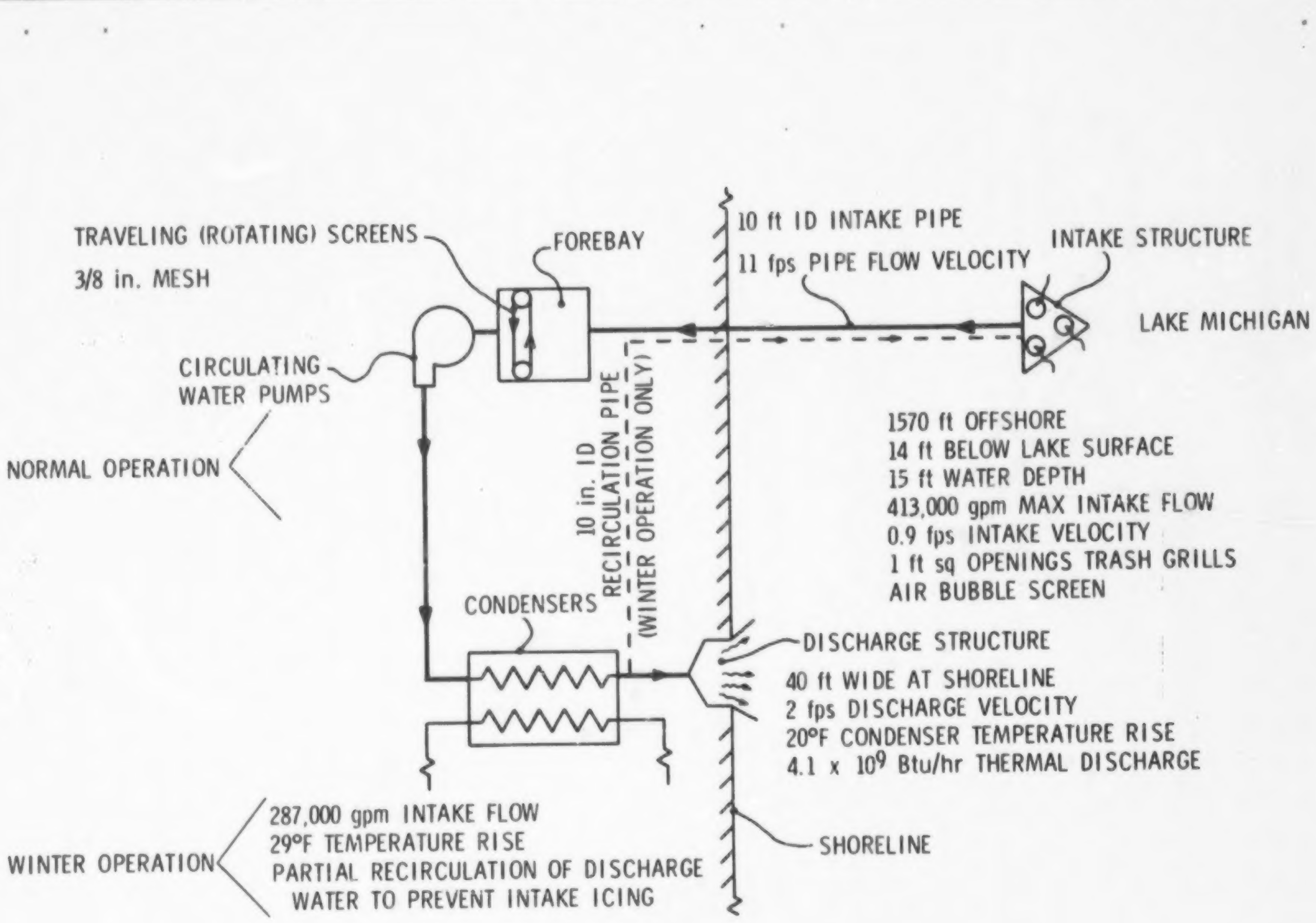


Fig. 5. Schematic of Kewaunee Condenser Cooling System

Under this operation, a portion of the discharge water is returned to the intake via a 10-in. recirculation line. Figure 6 shows the intake and discharge structures in much greater detail.

2. Point Beach Plant Cooling System

The condenser cooling-water system for the Point Beach Plant is schematically shown in Fig. 7. The Point Beach Plant has two generating units and, therefore, two independent condenser cooling systems. The intake structure is made of steel piling forming a hollow cylindrical structure, standing upright on the lake bottom, and filled with staggered limestone blocks. In addition, thirty-eight 30-in.-dia pipes pass through the intake structure about 5 ft above the lake bottom. The lakeside ends of these pipes are covered with $1\frac{3}{16}$ x 2-in. gratings. Figure 8 is an isometric view of the intake design. Most of the intake water flows through the void spaces between the limestone blocks. The isometric sketch is not correctly drawn, because the blocks are shown closely fitted when in reality they are somewhat more randomly oriented.

During normal, as opposed to wintertime, operation, both 14-ft-dia intake pipes are used to conduct the water to the plant screenhouse forebay. At full flow, the water velocity in both intake pipes can approach 5.4 fps. After entry into the forebay, the water passes through bar grates spaced about 2 in. apart, then through traveling screens using 3/8-in. mesh size. The design water velocity through the screens is about 1.1 fps. The debris collected on the traveling screens is sluiced to a strainer basket having 3-in.-square openings. The small-sized debris and the wash water are returned to the Unit 2 discharge flume. After passing through the traveling screens, the water divides between the circulating pump intakes for the two units. From this point on, the two cooling systems are independent, each having its own pumps, condensers, and discharge structures (outfalls). Both discharges are nominally 35-ft-wide canals extending out into the lake approximately 150 ft. Each outfall is at a 60° angle with shore. The average water discharge velocity within the flume is about 2.2 fps.

During winter operation, or whenever the intake water temperature falls below 40°F, 108,000 gpm of the discharge water is recirculated to the intake structure to prevent the formation of ice in the cooling system. This is accomplished by reversing the flow in one of the 14-ft intake pipes. At this time, the other pipe will maintain a higher intake flow of 428,000 gpm. Under these flow conditions and while at full plant power, the temperature rise for the cooling water will be about 31.5°F, instead of the normal 19.3°F rise.

3. Zion Station Cooling System

The schematic flow diagram for the Zion Station condenser cooling system is shown in Fig. 9. Details of the intake structure are shown

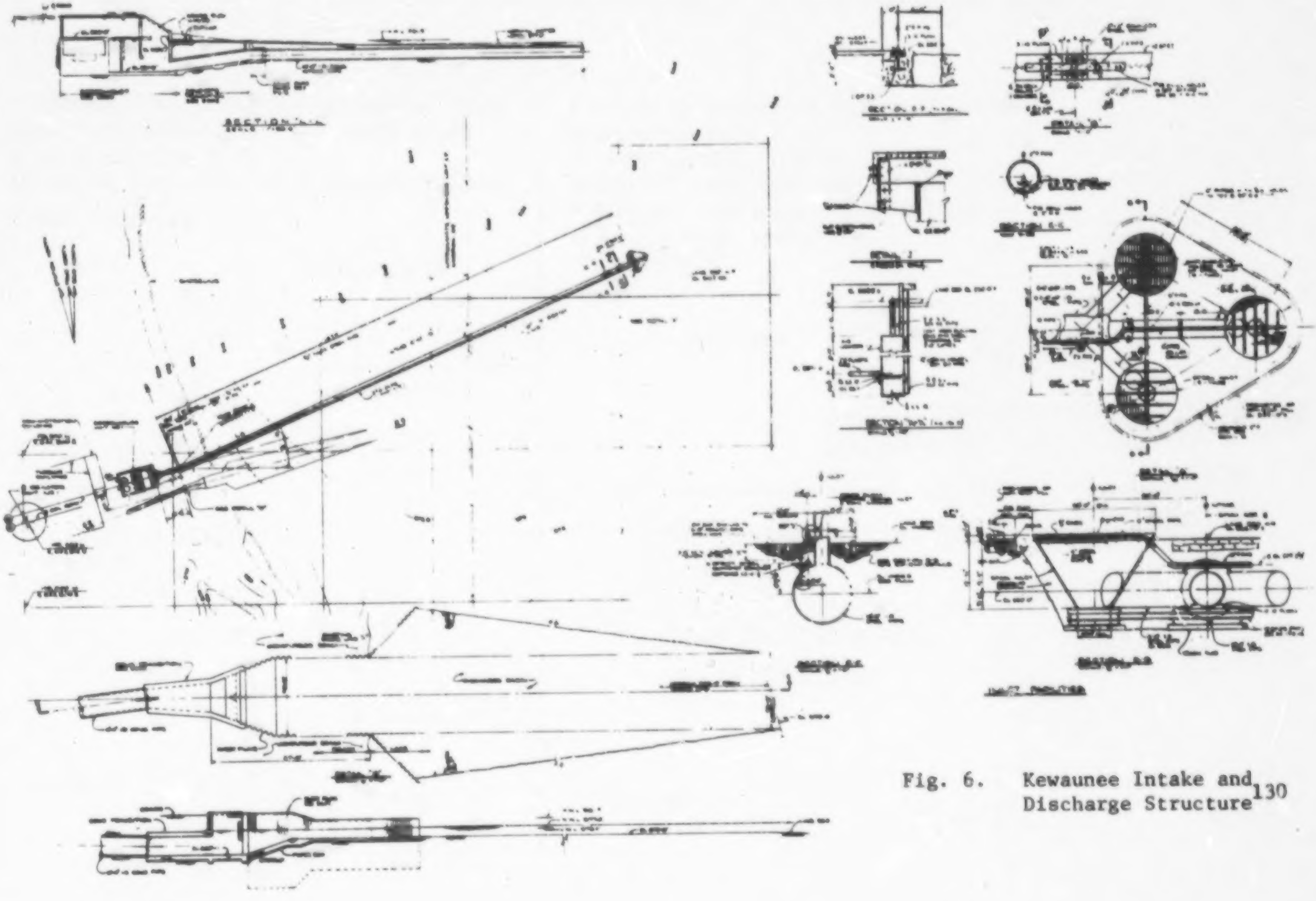


Fig. 6. Kewaunee Intake and Discharge Structure[130]

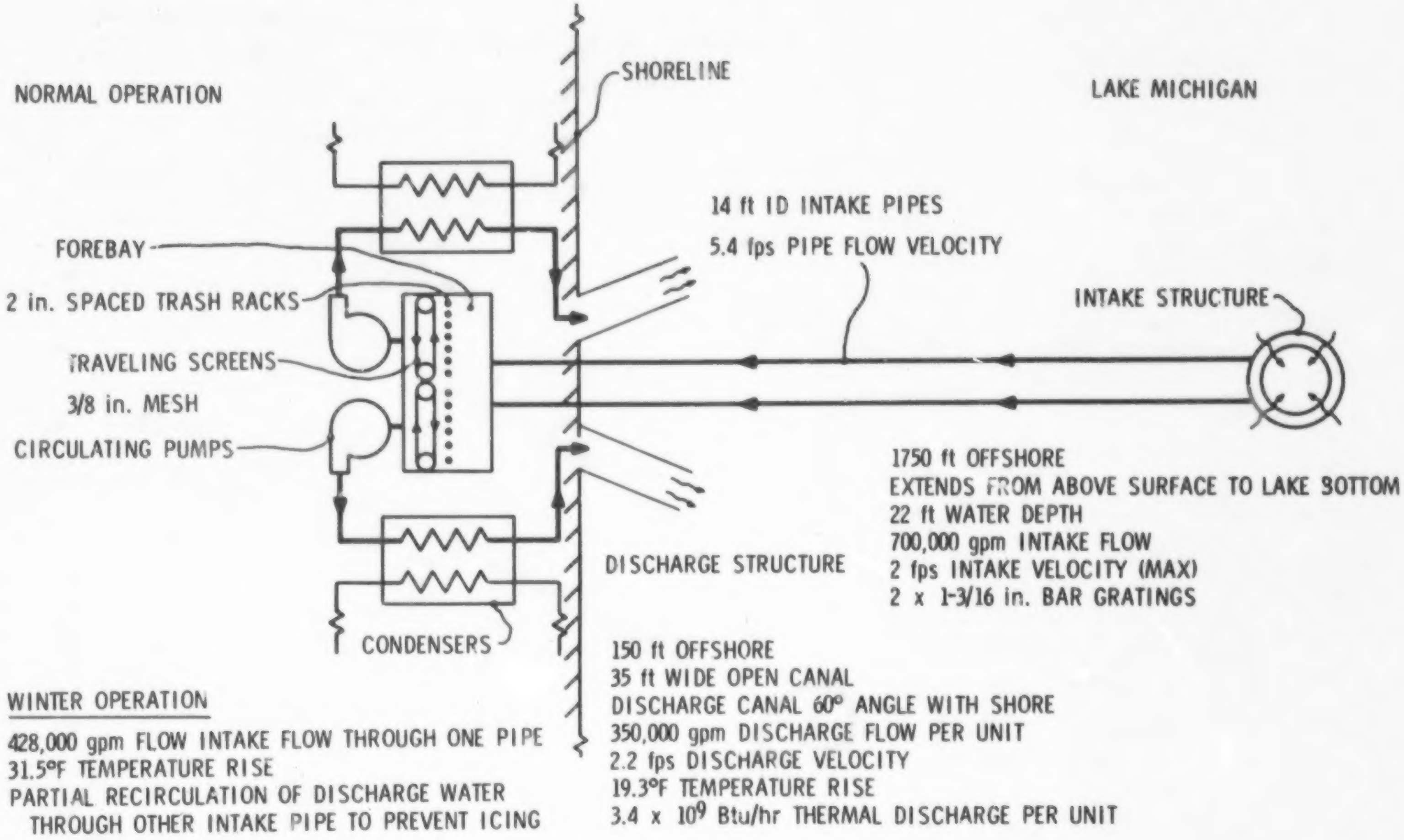

NORMAL OPERATION
SHORELINE
LAKE MICHIGAN
FOREBAY
2 in. SPACED TRASH RACKS
TRAVELING SCREENS
3/8 in. MESH
CIRCULATING PUMPS
CONDENSERS
14 ft ID INTAKE PIPES
5.4 fps PIPE FLOW VELOCITY
INTAKE STRUCTURE
1750 ft OFFSHORE
EXTENDS FROM ABOVE SURFACE TO LAKE BOTTOM
22 ft WATER DEPTH
700,000 gpm INTAKE FLOW
2 fps INTAKE VELOCITY (MAX)
2 x 1-3/16 in. BAR GRATINGS
DISCHARGE STRUCTURE
150 ft OFFSHORE
35 ft WIDE OPEN CANAL
DISCHARGE CANAL 60° ANGLE WITH SHORE
350,000 gpm DISCHARGE FLOW PER UNIT
2.2 fps DISCHARGE VELOCITY
19.3°F TEMPERATURE RISE
3.4 x 10⁹ Btu/hr THERMAL DISCHARGE PER UNIT
WINTER OPERATION
428,000 gpm FLOW INTAKE FLOW THROUGH ONE PIPE
31.5°F TEMPERATURE RISE
PARTIAL RECIRCULATION OF DISCHARGE WATER
THROUGH OTHER INTAKE PIPE TO PREVENT ICING

Fig. 7. Schematic of Point Beach Condenser Cooling System (two units)

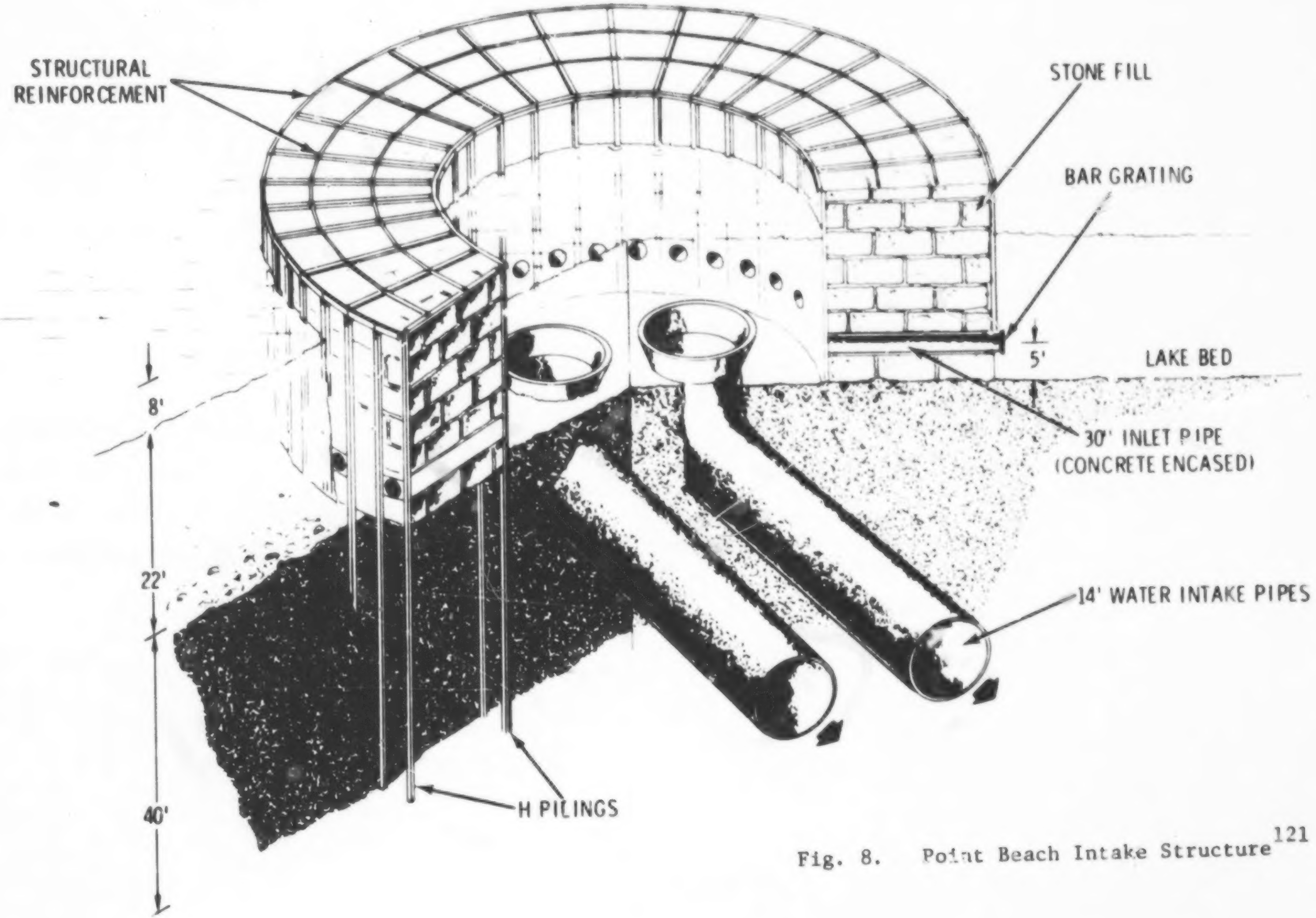


Fig. 8. Point Beach Intake Structure[121]

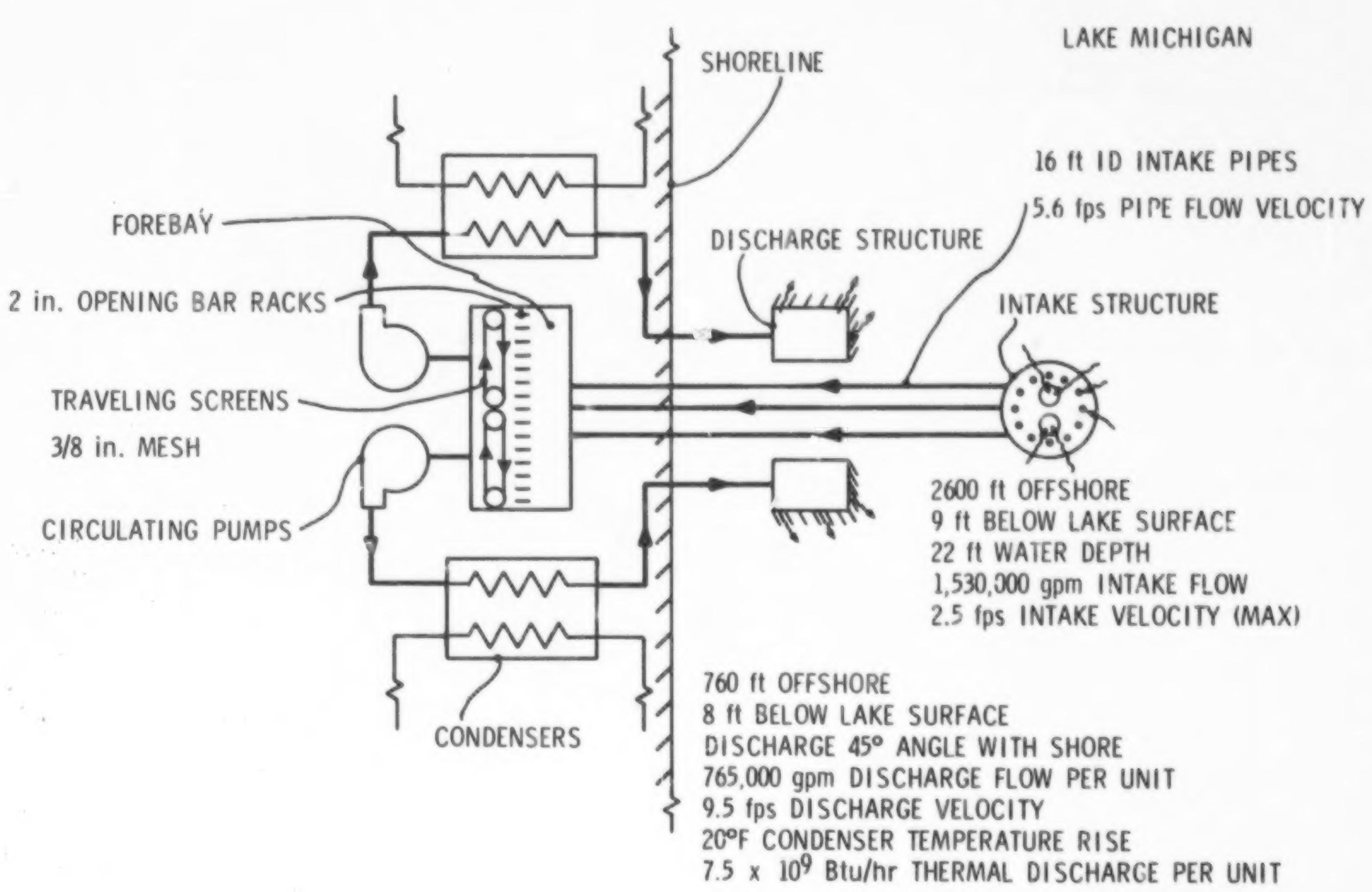


Fig. 9. Schematic of Zion Condenser Cooling System (two units)

in Fig. 10. The inlet ports are about 17 ft below the water surface. The roof structure is located above the two large intake ports to prevent vortex motions in the inlet water, as well as to provide more of a horizontal velocity gradient around the intake. Water not only enters through the larger two center ports but additionally through 45 small-diameter holes located around the periphery of the intake. These smaller ports serve a double purpose. In the wintertime, warm discharge water is recirculated through them to prevent system icing. These smaller ports eventually lead to the center intake pipe shown in Fig. 10, via a common plenum, the thawing box. All three 16-ft-dia intake pipes lead to the forebay. At full circulating flow, the average water-intake velocity at the two larger ports will be 2.47 fps while the 16-ft intake pipes will have a 5.6-fps average flow velocity.

An isometric drawing of one of Zion's 12 traveling screens is shown in Fig. 11. The bar grill has vertical 2-in. openings. The flow velocity will be 1.2 fps at the grill face and about 2 fps at the traveling screens. After passing through the screens, the water is withdrawn by the respective circulating pumps for each unit and eventually is discharged to the lake about 760 ft offshore. The total transit time from intake to discharge is about 2 min. The discharge structure for Unit 2 is shown in Fig. 12. The discharges are 154 ft on either side of the centerline for the intake pipes. Each structure consists of a rectangular box with outlet louvers located on the offshore end and on the side away from the intake pipes. The outlet from the discharge structure consists of 14 ports roughly 7 ft wide by 3 ft high. The ports are directed so as to form a 45° angle with both the intake lines and the shore.

During winter operation, part of the discharge water is recirculated to the intake structure by flow reversal in the central 16-ft-dia intake pipe. The cooling-water circulation rate and temperature rise for winter were not specified.

4. D. C. Cook Plant Cooling System

The condenser cooling-water system for the Cook Plant is schematically shown in Fig. 13. The intakes are surrounded by octagonal-shaped, heavy structural frames provided with bar racks and 8 by 8-in. grating on all sides. The top of each frame is covered with a steel roof. At full flow, the intake water velocity through the grating interstices will be 1.27 fps. Figure 14 shows a vertical view of a typical intake structure along with the grills of parallel vertical bars with $2\frac{5}{8}$-in. openings between them. The water velocity through the grills is about 1 fps. The traveling screens have 3/8-in.-square openings, and the water velocity through the screens will be at most 2 fps. The debris collected by the screens will be removed as solid waste. Units 1 and 2 have different condenser cooling-water flow requirements due to differences in turbine designs.

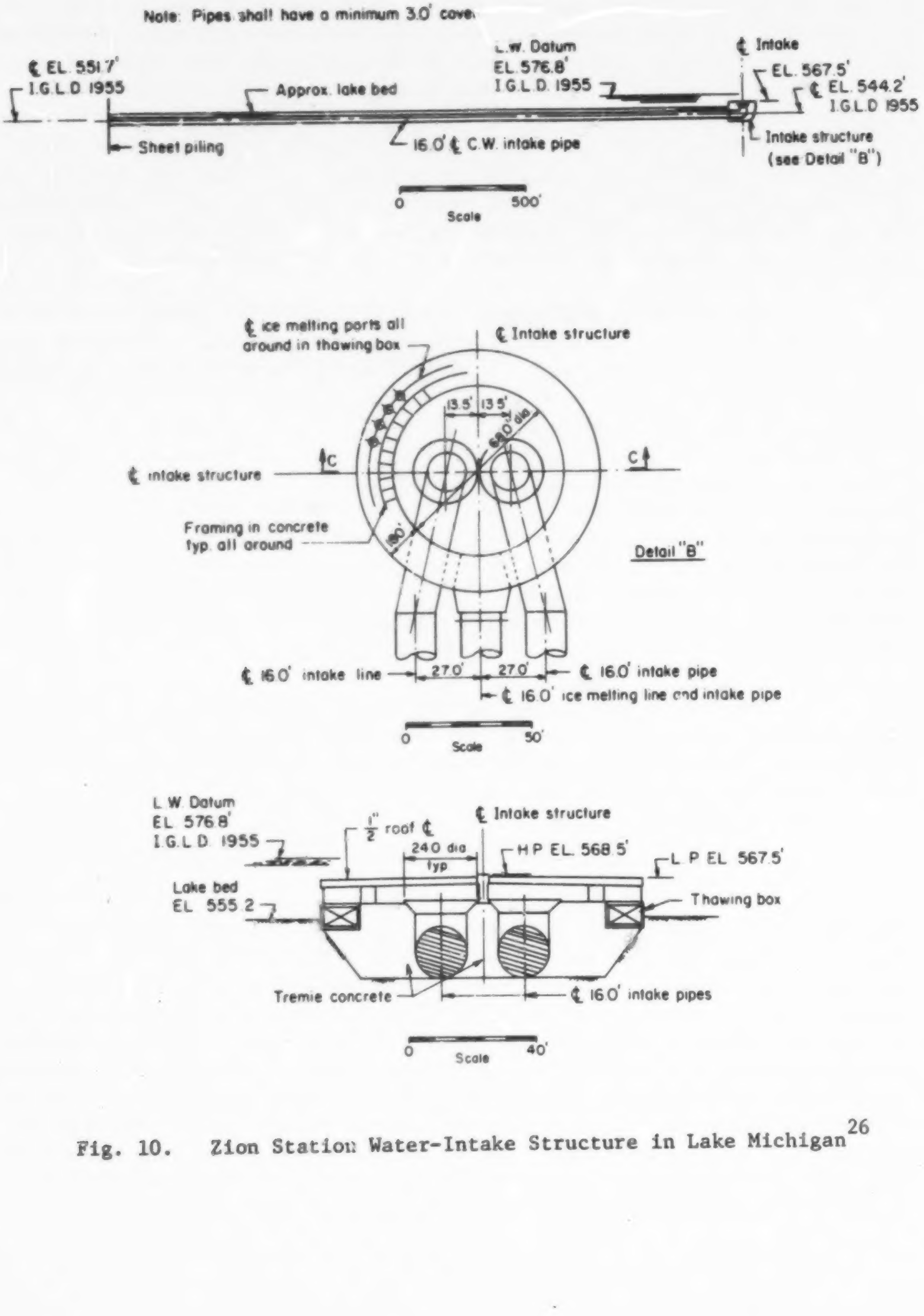


Fig. 10. Zion Station Water-Intake Structure in Lake Michigan[26]

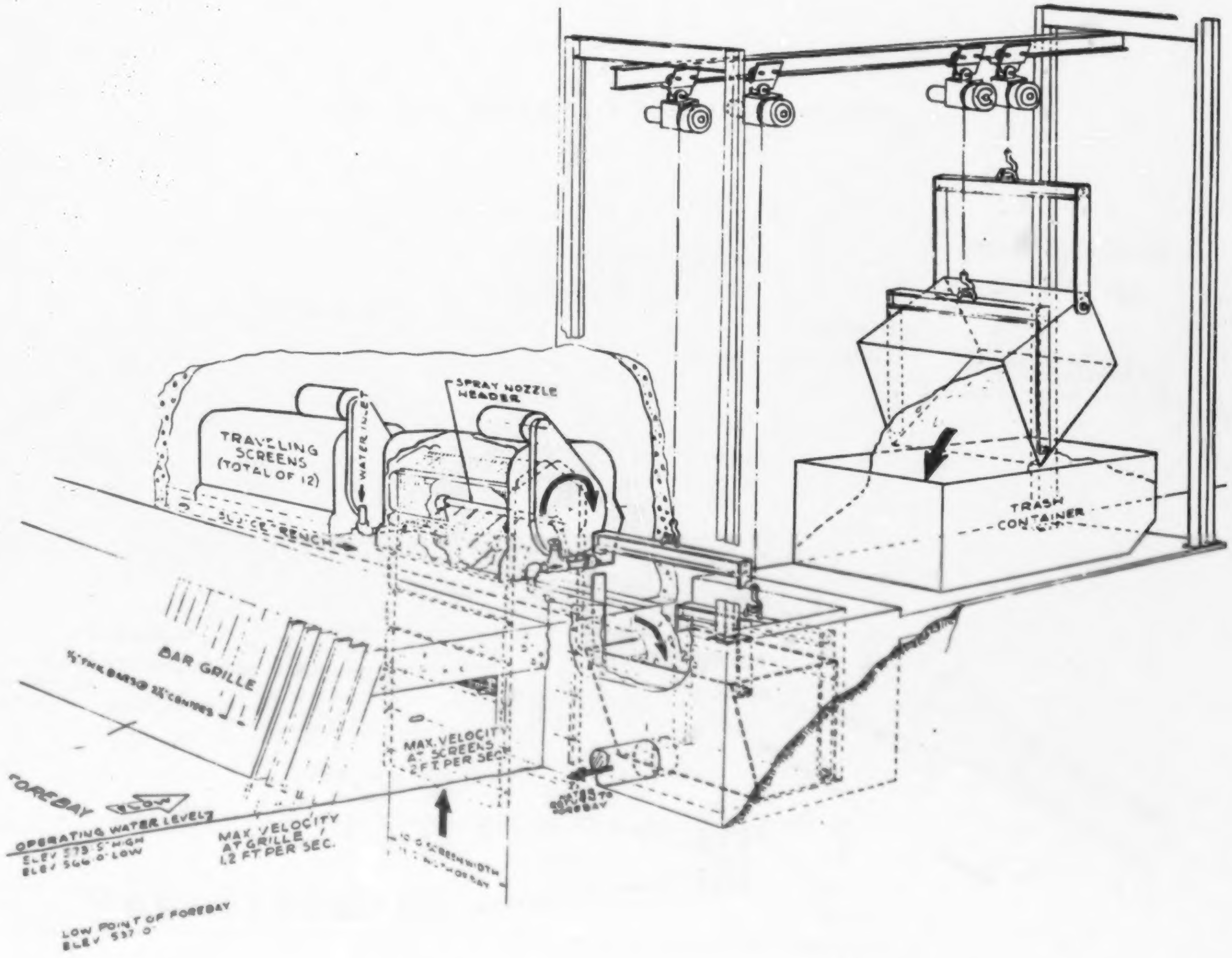


Fig. 11. Zion Traveling Screens[26]

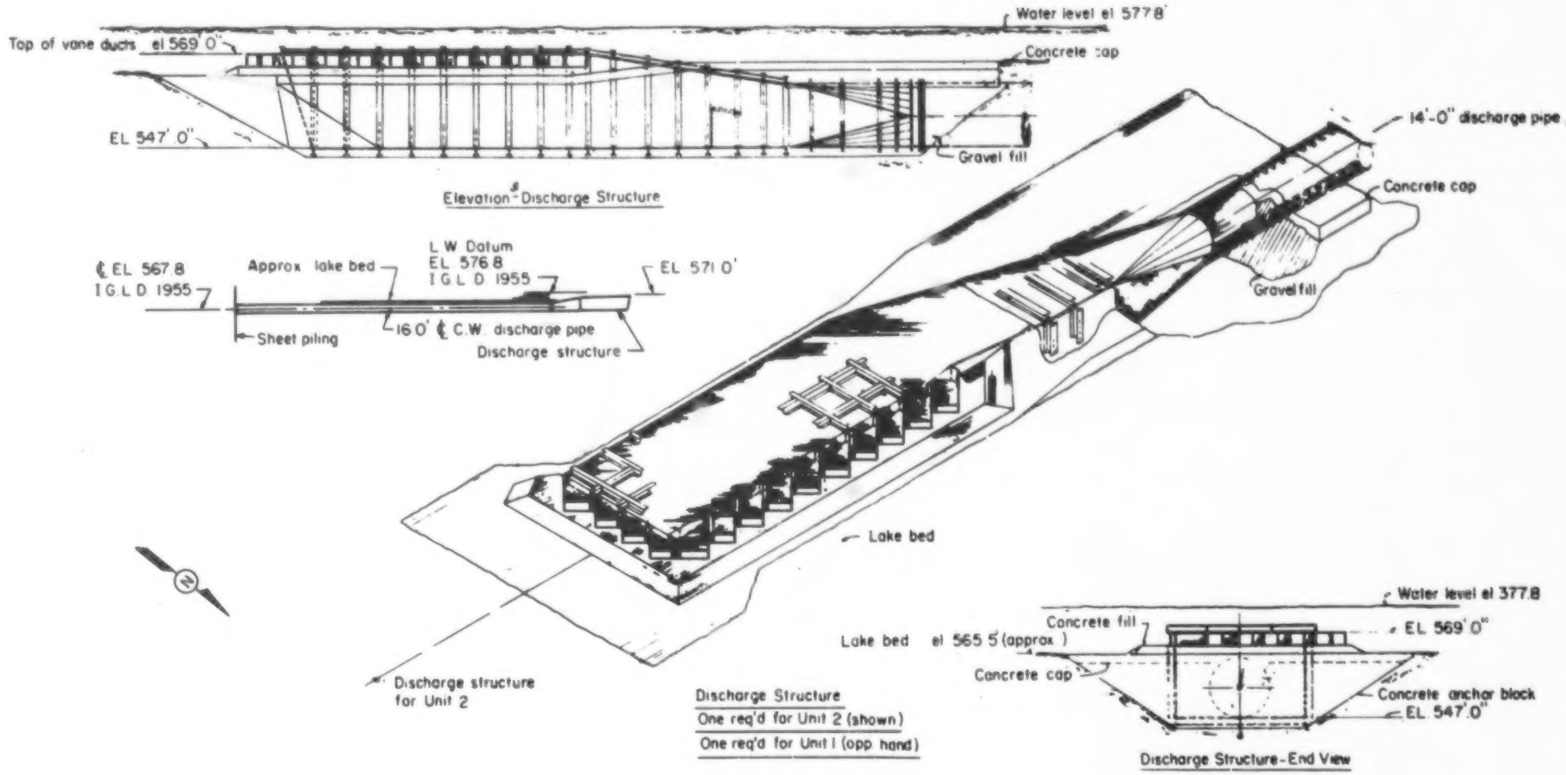


Fig. 12. Zion Unit 2 Discharge Structure[26]

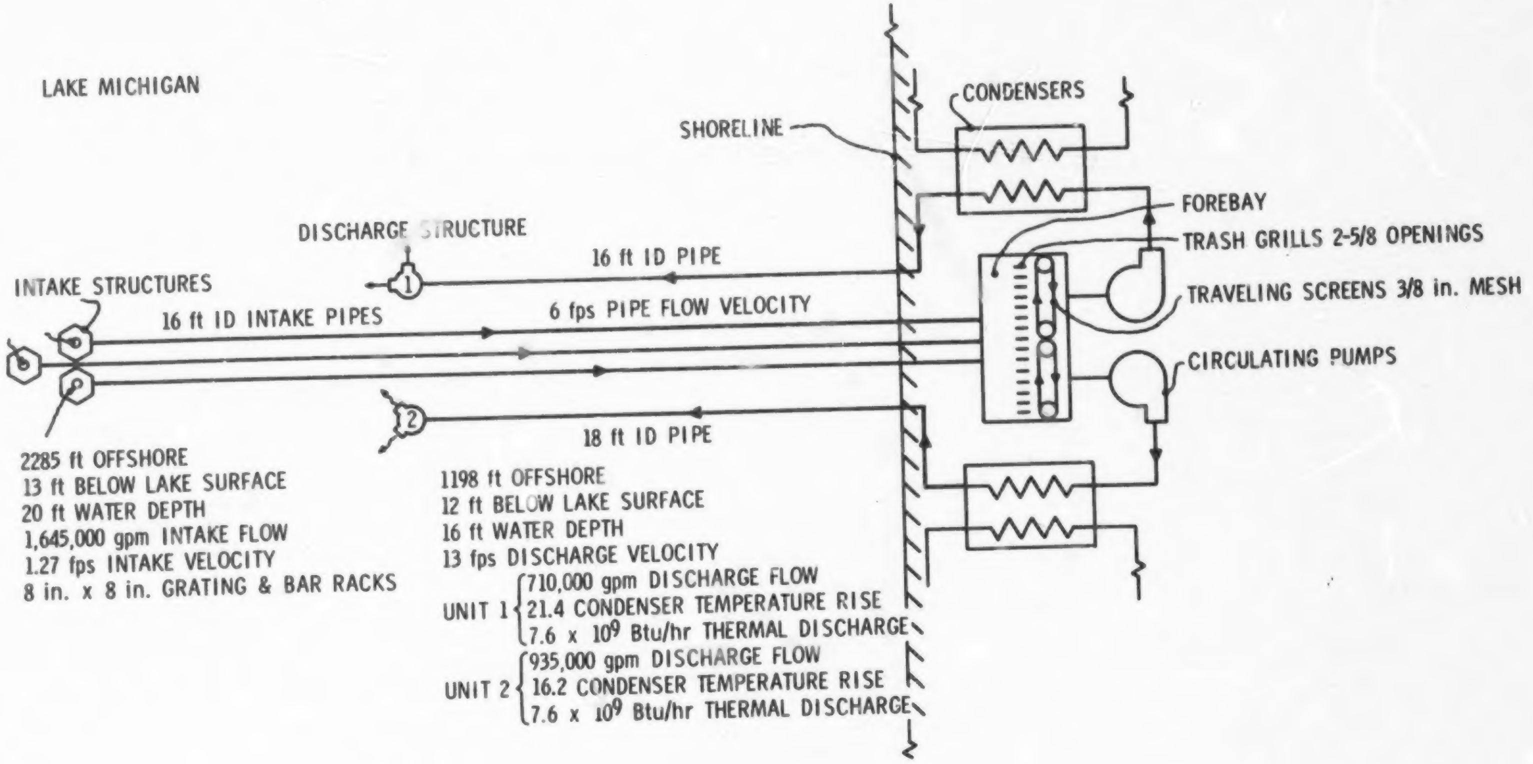

LAKE MICHIGAN
SHORELINE
CONDENSERS
FOREBAY
TRASH GRILLS 2-5/8 OPENINGS
TRAVELING SCREENS 3/8 in. MESH
CIRCULATING PUMPS
DISCHARGE STRUCTURE
INTAKE STRUCTURES
16 ft ID PIPE
16 ft ID INTAKE PIPES
6 fps PIPE FLOW VELOCITY
18 ft ID PIPE
1
2
2285 ft OFFSHORE
13 ft BELOW LAKE SURFACE
20 ft WATER DEPTH
1,645,000 gpm INTAKE FLOW
1.27 fps INTAKE VELOCITY
8 in. x 8 in. GRATING & BAR RACKS
1198 ft OFFSHORE
12 ft BELOW LAKE SURFACE
16 ft WATER DEPTH
13 fps DISCHARGE VELOCITY
UNIT 1
710,000 gpm DISCHARGE FLOW
21.4 CONDENSER TEMPERATURE RISE
7.6 x 10^9 Btu/hr THERMAL DISCHARGE
UNIT 2
935,000 gpm DISCHARGE FLOW
16.2 CONDENSER TEMPERATURE RISE
7.6 x 10^9 Btu/hr THERMAL DISCHARGE

Fig. 13. Schematic of Cook Condenser Cooling System (two units)

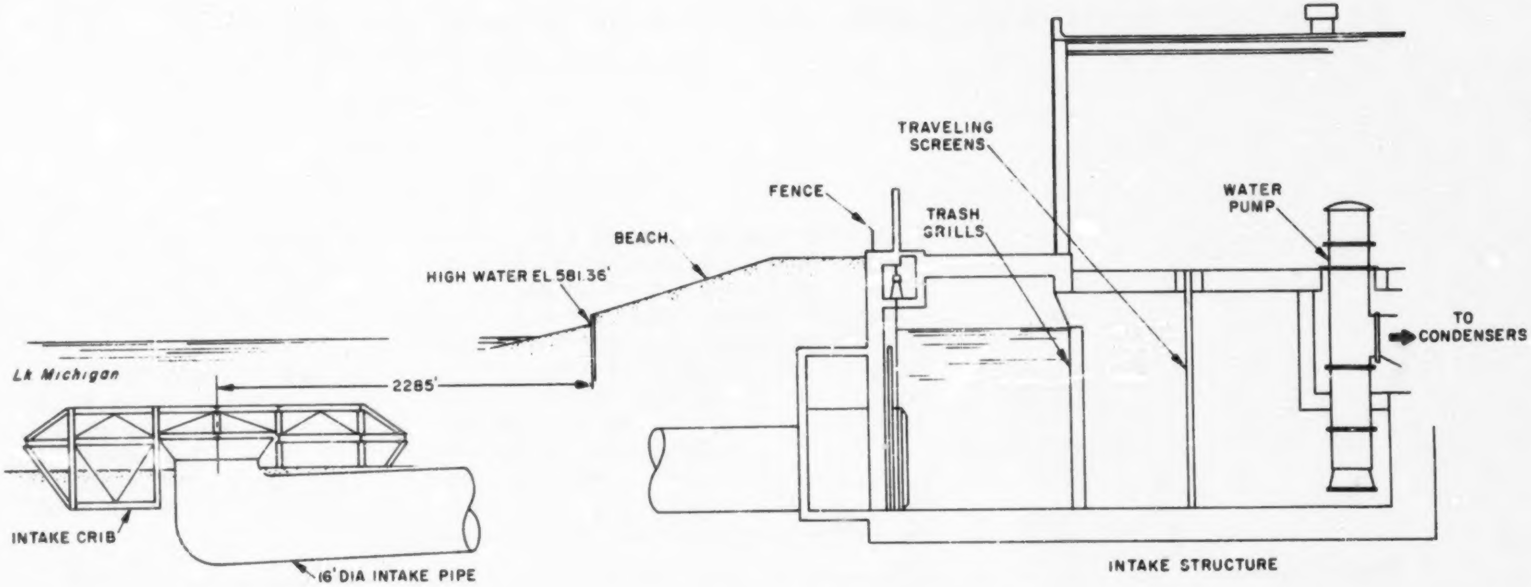


Fig. 14. Donald C. Cook Intake System Schematic[64]

Specific details concerning the discharge-structure designs are lacking. It is known that the structures will be located about 1198 ft offshore and will be submerged. The lake depth at the discharge locations will be about 16 ft. Each structure will extend about 4 ft above the lake bottom and will have two horizontal slot openings to produce a water-jet exit velocity of 13 fps. Details concerning the orientation of the jet openings are not given. Figure 15 shows a plan view in detail of the Cook circulating water system. The cooling-water transit time from the circulating pump discharge to the condenser inlet is about 35 sec. The transit time through the condensers is about 6 sec and from the condenser outlet to the point of discharge into the lake is about 184 sec.

Winter-season deicing capability is provided by recirculating a portion of the warmed discharge water from either Unit 1 or 2 through the center 16-ft-dia intake pipe in which flow will be reversed. Close inspection of Fig. 15 can show how this is accomplished by appropriately manipulating roller gates and sluice gates in the screenhouse. Specific flow and temperature data for the cooling system operating in the winter mode was not given.

5. Palisades Plant Cooling System

The schematic for the Palisades Plant condenser cooling system is shown in Fig. 16. Cooling water is withdrawn from the lake at about 3300 ft offshore. The intake consists of a vertical 11-ft-dia pipe, with its opening located about 6 ft from the lake bottom. A 60-ft-wide, 60-ft-long, 12-ft-high box is centrally located over the intake. The box has a steel plate for its top and 2-in. vertical bars, spaced 10 in. apart, around the sides. The trash rack located inside the screenhouse consists of a grating with vertical bars about 1 in. apart. The discharge canal is a structure about 37 ft wide at the shore, opening to 100 ft at the point of discharge, about 108 ft from shore. The average discharge velocity across the 100-ft-wide opening will generally be less than 2 fps. The cooling-water transit time from the condenser header to the point of discharge into the lake is roughly 25 sec.

During winter operation, about 17,000 gpm of discharge water will be withdrawn from the discharge canal and returned to the intake. A special pump will be used for this purpose.

B. Biological Effects

As stated in Section III.B, this section includes summaries of studies performed primarily in the intake and discharge canals. Similar types of studies that included measurements in the lake part of the plume are reported in the above-mentioned section. Therefore, reference to both sections will be necessary for a complete review.

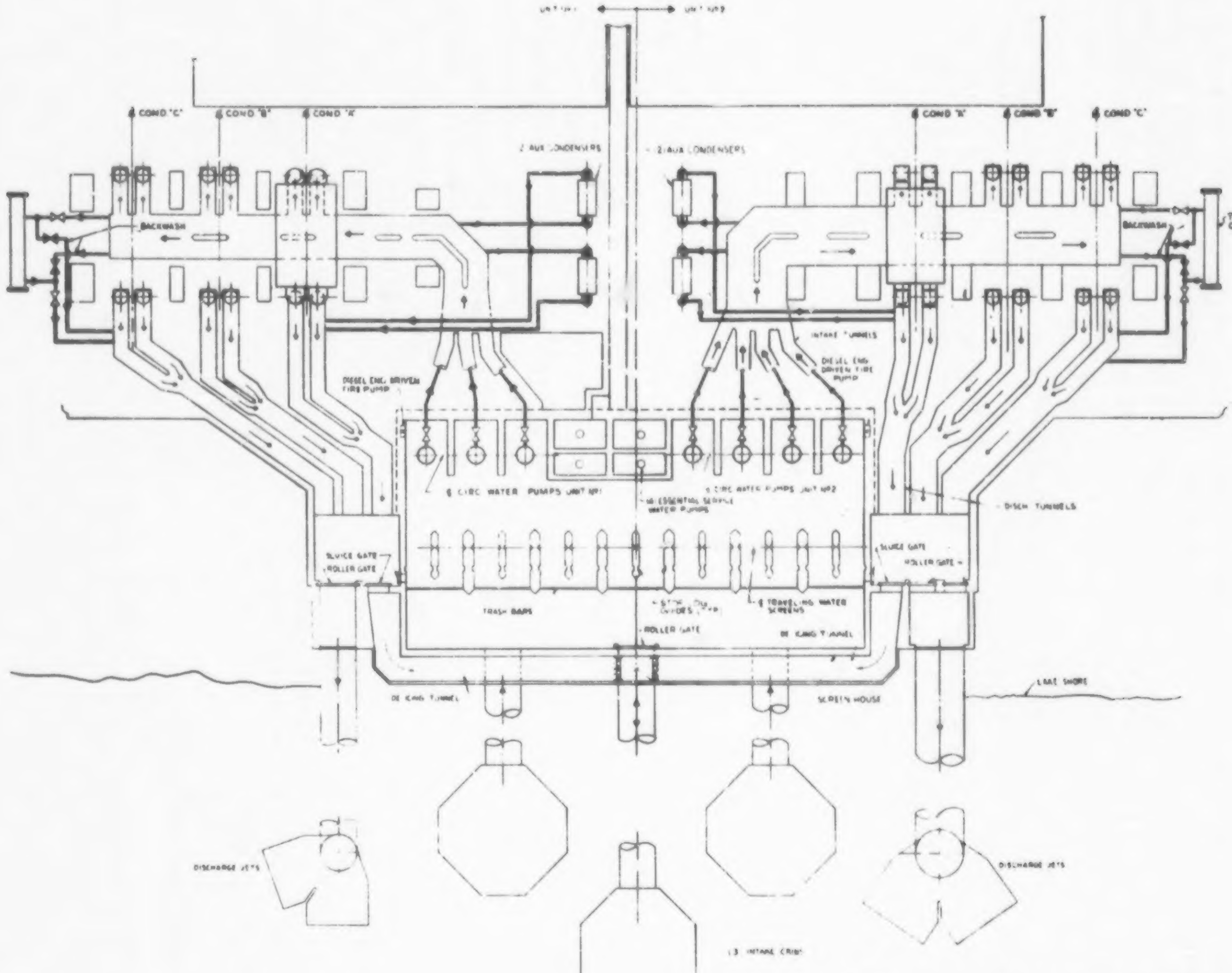


Fig. 15. Donald C. Cook Nuclear Plant Circulating System, Units 1 & 2[64]

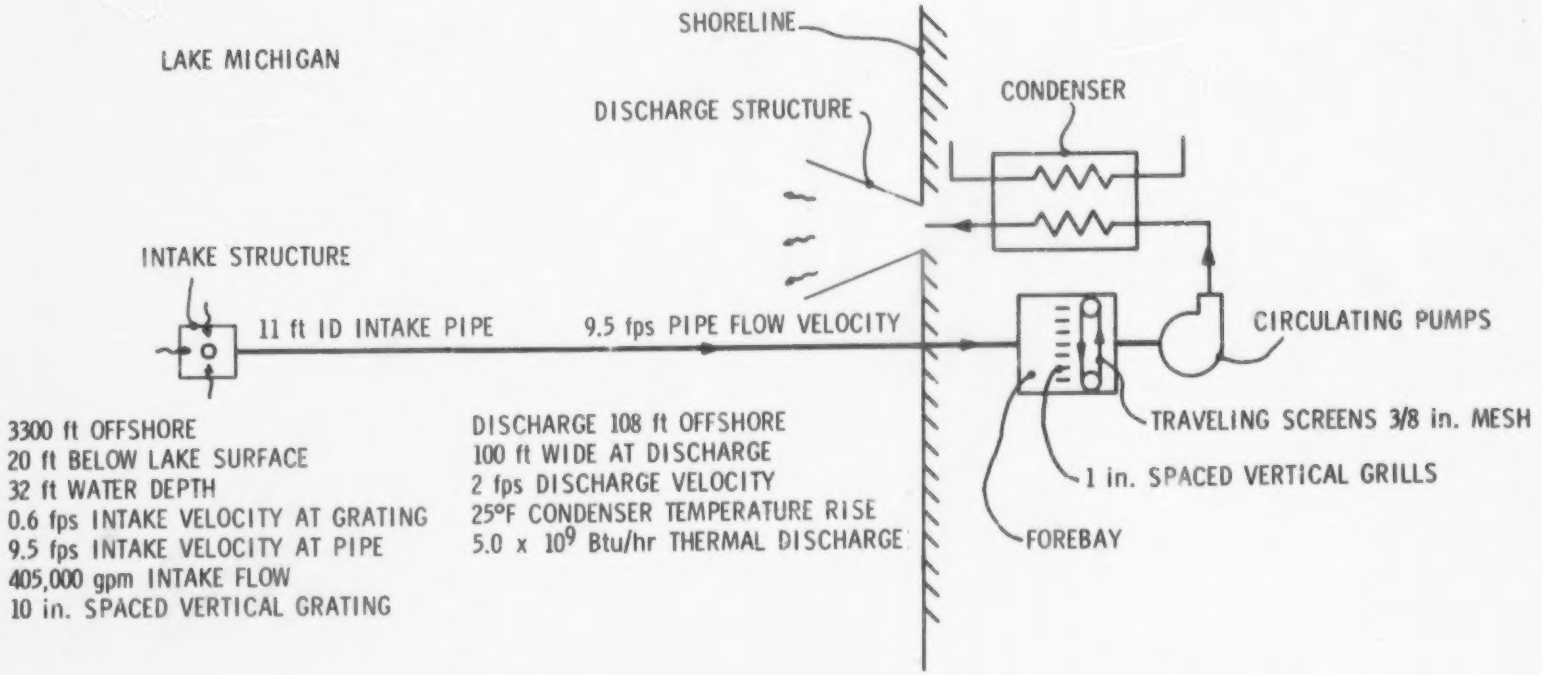

LAKE MICHIGAN
SHORELINE
DISCHARGE STRUCTURE
CONDENSER
INTAKE STRUCTURE
11 ft ID INTAKE PIPE
9.5 fps PIPE FLOW VELOCITY
CIRCULATING PUMPS
TRAVELING SCREENS 3/8 in. MESH
1 in. SPACED VERTICAL GRILLS
FOREBAY
3300 ft OFFSHORE
20 ft BELOW LAKE SURFACE
32 ft WATER DEPTH
0.6 fps INTAKE VELOCITY AT GRATING
9.5 fps INTAKE VELOCITY AT PIPE
405,000 gpm INTAKE FLOW
10 in. SPACED VERTICAL GRATING
DISCHARGE 108 ft OFFSHORE
100 ft WIDE AT DISCHARGE
2 fps DISCHARGE VELOCITY
25°F CONDENSER TEMPERATURE RISE
5.0 x 10⁹ Btu/hr THERMAL DISCHARGE

Fig. 16. Schematic of Palisades Condenser Cooling-Water System

The biological effects on organisms passing through the pumps and condensers were studied by the Bio-Test Laboratories at the Waukegan Generating Station during 1971.[72] Phytoplankton samples taken during this period indicated no significant differences in total population densities between the intake and discharge canals. (Ayers et al. reported an apparent 10% phytoplankton kill in his Waukegan measurements.[6])

Initial findings of the effects of zooplankton passing through the condensers[72] showed an average mortality of 5.8% due to mechanical effects and another 1.6% due to thermal stress. (Comparisons were made with and without heat addition in the condensers.) Even in July and August, when the discharge water reached a maximum temperature of 88°F, 90% of the zooplankton survived. Other studies[10,22,58,90] (some of which relate to saltwater) were cited as showing that water temperatures below 99°F have little effect on the survival rate of most zooplankton. However, they found over 80% mortality when this temperature was exceeded.[72]

Size was found to be an important factor in the mortality rates. Zooplankton exceeding a length of 0.9 mm suffered 17% mortality; smaller organisms suffered only 4% mortality[72]

Reference 72 cited studies that showed, "Organisms subjected to a sudden temperature rise occasionally assume a condition of complete inactivity simulating death. However, within a few hours after being returned to temperatures far below their lethal level, these 'dormant' organisms would resume their normal active conditions."[23] The zooplankton population at the Waukegan Station showed an average recovery rate of 1.4% 4 hr after entrainment, resulting in a total mortality of only 6% from condenser passage.[72]

Preliminary studies at Waukegan indicated condenser passage had little if any lethal effect on zooplankton egg viability. Results from September to December 1971 showed, in each of four species tested, egg viability increased from 1 to 7% as a result of passage through the condenser.[72]

Periphyton samples collected from April 1970 to March 1971, from artificial substrates in the Waukegan intake and discharge canals, indicated more rapid growth in the warm discharge water during June and July. The increased growth was due to nonfilamentous green algae, periphytic diatoms, and filamentous blue-green algae, and not to forms of Cladophora. Growth in the discharge canal was reduced during midsummer when water temperatures exceeded 70°F. After September the growth again increased, but was not as large as that which occurred on substrates located away from the influence of the warmed water.[74]

Samples taken during 1971 (Ref. 72) showed that, as in the 1970 study,[74] the dominant members of the periphyton community in both the intake and discharge canals were diatoms. Despite some differences in distribution and abundance of particular species between the intake and discharge, the total species, composed mainly of diatoms, was often quite similar. The green algae species, Stigeoclonium, which was found to be abundant in the discharge canal only in late June 1970, proliferated in both canals in the 1971 sampling period. It was abundant in the intake when temperatures ranged from 50 to 60°F, but also grew well in the discharge temperatures of 70-79°F. Both the intake and discharge supported much larger growths of periphyton in December 1971 than in December 1970.

The thermal discharge from the Point Beach Nuclear Plant has been the subject of a number of studies since the unit went into operation in December 1970. Reference 128 describes a preliminary study, primarily to develop experimental techniques, that used the two separate cooling systems to study the mechanical damage and combined mechanical-thermal damage on phytoplankton and zooplankton. Although experimental difficulties were experienced, the preliminary results indicated no significant mortality to phytoplankton. Samples of zooplankton taken from the intake and discharge of both units were similarly surveyed, and results show that the physical damage incurred by passage through the plant was more critical than the thermal impact. That is, the lethal effects of heating and pumping were essentially the same as the effects of pumping alone. The percentage of animals killed by the entrainment experience varied from 8 to 19%, depending upon the season.[121]

Testimony given at the Wisconsin hearings[125] by Dr. Wright, Westinghouse Environmental Systems Department, described results of studies (unreferenced) by his organization at "a variety of locations throughout the United States." Problems related to flow were generally more significant than those related to the increased temperatures. Phytoplankton survive both the passage through the condenser and the residual time in the thermal plume and still maintain their photosynthetic activity. In some cases, there was an increase in the productivity within the plume. Depending on the species and life stages sampled, a 5-20% loss in mobility of zooplankton was observed as a result of passage through the pumps and condenser.

Studies on whitefish egg entrainment and effects on phytoplankton and zooplankton productivity, as a result of passage through the intake structures, pumps, and condensers, were reported by the EPA Grosse Ile Laboratory.[44] Samples were taken daily at the Big Rock Nuclear Plant during November 1971 and at the Escanaba Power Plant during November 30-December 4, 1971. These plants were chosen because of their proximity to whitefish spawning grounds.

After pumping more than 6 million gallons of intake water at the two plants, the investigators reported finding no eggs at the Big Rock intake and an insignificant number in the Escanaba intake. The results on phytoplankton productivity were inconclusive because of a low and variable population density at the intake.[44]

The low live/dead zooplankton ratio at the Big Rock Plant inlet indicated that damage was inflicted on the zooplankton while being drawn through the intake pipe (2000 ft offshore) or the population was adversely affected by severe storms during the sampling period. The differences in the live/dead ratios between the inlet and discharge was equivalent to a 55% mortality of the population observed. The mortality would be 29% if the discharge live/dead ratio were applied to the forebay population. They concluded, "Regardless of whether the mortality is 29 or 55%, there appears to be significant population mortality."[44]

The live/dead zooplankton ratios obtained at the Escanaba Plant were much higher than those observed at Big Rock. The higher survival rate could have resulted because of less stress imposed upon the organisms by the shoreline intake. The data indicated a 7% mortality in passing through the plant.

Brauer _et_ _al_.[16] studied the influence of the intake and outfall on the distribution and abundance of zooplankton in Lake Monona. Sampling on 13 days in the summer and fall of 1969 and 1970 showed that _Diaptomus_, _Daphnia_ and cyclopoid copepods were two to seven times as abundant in the water near the outfalls as in the control area. The maximum zooplankton density occurred in or very near the discharge currents, which suggested that the animals were being brought into the plume area rather than being produced in situ. Observations that a many-fold increase in zooplankton density took place in periods as short as 6 hr after the pumps were started, plus the fact that the ratio of young to adult animals in the outfall samples was not noticeably high, support the conclusion that the organisms were brought into the area via the intake. This continuous input of zooplankton simulated a rapid local production of zooplankton and probably contributes to a higher concentration of fishes in the outfall area than in the reference area.[16]

The studies indicated that judicious location of intakes (at a depth of minimum organism densities) is one way in which a power company could reduce its biological effects.

Personnel of the Wisconsin Department of Natural Resources collected samples from the Point Beach discharge canal to determine to what extent fish eggs and fry were drawn through the cooling-water system.[76] Samples were collected on 14 days during March 3-May 27, 1971. The specimens recovered consisted of one sculpin (partially deteriorated), a few smelt eggs, and one salmonid egg (white). Since whitefish and lake herring are late fall and winter spawners, the sampling was discontinued until November, at which time sampling was performed twice a week until March 1972. This time the specimens consisted of $4\frac{1}{3}$ smelt (2-3 in.), two salmonid eggs (white), and one small unidentified egg. The investigators concluded from these studies that the intake and discharge structures from the Point Beach Unit No. 1 are of negligible concern to the spawning grounds, eggs, and fry of whitefish and lake herring in Lake Michigan.

Operating experience with entrainment of fish during interim operation at low power is summarized in Ref. 119 for the Palisades Nuclear Plant. The principal mortality was sculpins in January and February 1972. The total number of fish impinged on the screens and counted daily from February 24 to March 26, 1972, ranged from zero for 22 days up to 15 per day for 10 days.[119]

A large fish kill was reported at the J. H. Campbell Plant in early February 1971. The circumstances were summarized in a Michigan Water Resources Commission memorandum.[117] (1) The problem had existed for 7-10 days. (2) A rough estimate was that several hundred thousand fish had been killed by impingement on the screens. (3) The species were mostly gizzard shad, with some alewives and yellow perch. It was speculated that attraction of fish to the warm water that was discharged to prevent ice jams in the intake channel was the cause of the problem.

The occurrence of gas-bubble disease in fish in the discharge of a power plant in North Carolina was reported by the North Carolina Wildlife Resources Commission.[38] Gas-bubble disease can occur when the blood of a fish becomes supersaturated with gases. This condition may result when a fish at equilibrium with air-saturated water is subjected to an increase in temperature, a decrease in pressure, or both. More commonly, gas-bubble disease develops when a fish is exposed to an environment supersaturated with dissolved gases.[38]

Gill nets, electrofishing, and midwater trawls were used to obtain monthly fish samples at the Duke Power Company Marshall Steam Station. Three species of fish were found to be afflicted with the disease during the winter of 1969-1970, whereas 13 species showed symptons during the winter of 1970-1971. "Pop-eye" was the major diagnostic feature observed in the majority of cases. Relatively few fishes had bubbles on their head or fins, or in the mouth or the viscera.[38]

Several fish mortalities involving a few hundred black crappie were observed during late February 1971. The symptoms exhibited by the dying fishes implicated gas-bubble disease as a principal factor.[38]

Marcy[137] reported on the survival of fish larvae in the discharge canal of the Connecticut Yankee Atomic Power Plant. The plant cooling water, heated to about 22°F above ambient river water, is discharged into a 1.14 mile long canal before returning to the Connecticut River. Non-screenable fish larvae less than 0.6 in. in length, were sampled at the plant intake and discharge, and at three points along the canal. The studies revealed that no fish of nine species entrained in the condenser cooling-water system survived passage to the lower end of the canal when water temperatures were above 86°F. The survival rate immediately after passing through the plant was 34.5% when the discharge temperature was 82°F and 16.6% when the discharge temperature was 92°F. The majority of dead specimens were mangled, and this condition was more apparent in larger specimens. When the discharge temperature was 95°F, 100% mortality occurred during passage through the plant.

V. ALTERNATIVE COOLING METHODS

A. Environmental Impact

At the September 28, 1970, Workshop Session of the Third Lake Michigan Enforcement Conference, a report, entitled "Feasibility of Alternative Means of Cooling for Thermal Power Plants Near Lake Michigan" was entered into record by Federal EPA representatives. The object of this report was to establish the engineering and economic feasibility of various closed-cycle condenser cooling methods that could alternatively be used in the place of once-through cooling. The report examined the situation for a modern 40% efficient 1000-MWe fossil plant (or some plant with an equivalent thermal discharge loading) sited along four shoreline reaches of Lake Michigan. The alternatives considered were: mechanical and natural-draft evaporative cooling towers, mechanical and natural-draft "dry" cooling towers, cooling ponds, and spray canals. Representative meteorological data for the four reaches of the lake were obtained and then used as input data to computer codes to generate engineering performance and monetary cost data for the alternatives.

The report concluded that the alternative cooling systems considered are feasible alternatives to once-through cooling around Lake Michigan, and the impact of alternative cooling systems on the environment appears to be minor. Those potential problems that do exist with the alternatives could be avoided, or at least alleviated, through proper site selection and engineering design.

Several specific studies have been made concerning the possible environmental impact of alternative cooling systems for the major nuclear power stations sited on the Great Lakes. Presently, four of the 12 U.S. nuclear stations, either operating or under construction on the Great Lakes, will use closed-cycle cooling in the form of evaporative towers. Two of these plants are situated along Lake Michigan, and the other two on Lake Erie. Although this report is primarily concerned with Lake Michigan, it was felt that much of the environmental rationale concerning the installation of closed-cycle cooling at the two Lake Erie plants could be equally germane to Lake Michigan issues.

The following pages contain information extracted either from utility environmental reports or from U.S. AEC environmental statements made on nuclear power plants pursuant to the National Environmental Policy Act of 1969. The information is qualitative in nature. Nevertheless, this information is presented to give the reader additional perspective on the environmental issues surrounding closed-cycle cooling.

1. Davis-Besse Station

The 915-MWe Davis-Besse Station, on Lake Erie, will use a single 493-ft-tall natural-draft tower.[115] Studies of the climatic effects of an earlier proposed 370-ft tower, by Travelers Research Corporation, indicated that the tower would "emit a highly visible but elevated plume, which will, on the average, persist 1.2-2.3 miles downwind. It may, in cold weather, persist as much as 20 miles downwind an estimated 6% of the time (22 days)." The visible plume would touch the ground less than 2% of the time, on an annual basis. During rare winter conditions the tower plume could cause some icing on structures at or near ground level, at a distance of 1-2 miles from the tower, in the downwind direction.

More recent studies were performed by NUS Corporation for the actual 493-ft-high tower under construction at the Besse site.[115] Two-year site meteorological data were correlated with Toledo meteorological data, which, in turn, were used to predict the environmental effects of the operation of the cooling tower. Computer codes were used to calculate plume rise, dispersion, and transport on an hourly basis upon input of hourly meteorological data. The results were examined to determine consistency with the actual Besse site meteorological data and the occurrence of localized lake breeze effects, and also to assess anomalous situations of plume downwash. The NUS analysis concluded that the average visible vapor plume would be 1.5 miles long. Visible plumes longer than 5 miles were estimated to occur only 3% of the total hours of the year. As long as the plume remained aloft during these periods, the plumes would represent only an aesthetic problem.

It was further estimated that there could be a maximum annual increase of 3.5 hr in the occurrence of fog conditions resulting from tower operation. An annual average of 831 hr of fog occurs naturally; therefore the 3.5-hr figure represents a 0.42% increase. The increased occurrence of fog conditions does not represent discrete cases of induced fog, but rather the possibility of fog occurring earlier and lasting longer than normal. Lake breeze effects could increase the possibility of fog calculated for the study; however, this effect was not considered to be significant.

Predicted increases in induced fog under icing conditions were estimated to be less than 1 min at maximum. Lake breeze effects were not considered to change the icing calculations since the lake breeze is not a major effect during the winter, when the lake surface is generally warmer than the land surface.

Downwash conditions resulting in the plume being brought to ground elevation were calculated to occur as often as 12.8% of the time (1121 hr/yr), with most hours occurring under offshore winds. The winter downwash could possibly result in icing on surfaces less than 3000 ft away at a rate of 0.03-0.07 in. of ice per hour. These downwash calculations reflected maximum limits of occurrence and actual observations at operating natural draft towers in this country have not confirmed downwash behavior.

The Environmental Report[115] stated that the temperature excess of blowdown effluent over the ambient Lake Erie receiving water will be limited to a maximum of 20°F by supplying ambient lake water to a collecting basin to dilute the tower blowdown. The maximum quantity of heat discharged to the lake is expected to be no greater than 1.38×10^8 Btu/hr, as opposed to 62.10×10^8 Btu/hr for once-through cooling. This corresponds to a 45 to 1 reduction in heat input to the lake. The blowdown will enter the lake through an offshore high-velocity discharge with a normal flow of 9225 gpm. On occasions the flow may reach as high as 13,800 gpm.

Tower drift was estimated to be a negligible problem since the expected drift losses would be 0.01% of the tower circulating flow, or 48 gpm. For an assumed tower concentration factor of two and an assumed lake water salt content of 225 ppm, the maximum amount of salt deposited on the land was estimated to be 3.7×10^{-4} (lb/yr)/sq ft, assuming a uniform salt distribution over a 10-square-mile area. Assuming a 30.5-in. annual rainfall, the salt concentration was estimated to be 2 ppm if all the salt deposited was taken by the rain. Terrestrial effects arising from drift losses were therefore assumed to be of little concern.

The Environmental Report also addressed the potential impact of the tower on bird kills.[115] Collision kills with the tower by migratory waterfowl were considered to be most likely at night or during times of heavy fog, but in any event, they were assumed to be minor in relation to the total migratory populations. Resident birds were not expected to be destroyed by collisions with the tower.

2. Enrico Fermi Plant

The Fermi Plant environmental report indicates that two natural-draft evaporative towers, approximately 400 ft high, will be used for condenser cooling.[39] The report stated that the possible effects of the towers on the local environment can be conveniently considered to be of two kinds: (1) presence of water from the towers in the form of plumes, fog, icing, or precipitation; and (2) influence on natural condensation and precipitation processes. The report states, "The quantitative assessment of the two kinds of effects at this time can be made only from observations of releases from similar cooling towers in similar climates and from incomplete theoretical calculations."

Two early independent analyses of the extent of the tower plumes indicated that an airport two miles west of the plant might be influenced at most by 8-18 hr/yr. The diffusion models used to calculate these distances were credited with yielding unusually conservative values because they did not take into account the plume's inherent buoyancy. Additional estimates of the plume's horizontal extent were gained from observations of the Keystone natural-draft towers in western Pennsylvania.

For a six-month observational period, the plumes on only 11 different days extended as much as a mile. Although the climate in the Keystone plant area is somewhat different from that of southeastern Michigan, it is believed that the Keystone information offers a realistic idea of what can be expected at the Fermi site.[39]

Minor modifications of the microclimate in the vicinity of the Fermi site, resulting from plume shadowing, were anticipated. However, the actual effects or the magnitude of these effects has not been assessed. Fog formation was only discussed in a qualitative way. The inference was that it would take an unusual set of meteorological conditions to bring the tower plumes to the ground.

Ground icing conditions were stated to possibly arise under either of the following conditions: (1) With strong winds (>25 mph), there is a potential of downwash icing in the immediate vicinity of the towers, provided that there is the additional joint occurrence that objects downwind are below 32°F and the atmosphere has a high relative humidity. An analysis of 10-yr records of hourly observations at the Detroit City Airport showed that the joint occurrence of the above-mentioned conditions occurred for less than 0.1% of the observations. In any event, the extent of icing in this manner should be confined to an area two to four tower heights downwind. (2) Lake breeze circulations during early spring were also hypothesized as being the second possible means for causing ground icing. No estimates were given as to the potential number or duration of these periods. This issue, according to the report, awaits successful application of numerical models presently being formulated.

Comparative calculations were made assuming that if all the water evaporated from both towers over a year were evenly deposited over a 25-square-mile area, it would amount to 1.4 in. of precipitation. This is compared with a normal annual rate of about 31 in. The report went on to state that observations of actual cooling towers rarely show observable precipitation, and when precipitation did occur, it was not established whether it was the result of natural processes being stimulated by tower effluent.

The influence of tower effluents on natural condensation and precipitation processes was discussed. Although the total amount of heat and water released from a cooling tower is small in comparison to a small shower, the nature of the atmosphere is such that at times small perturbations may give rise to more extensive reactions. Several were enumerated and discussed:

a. Cumulus or stratocumulus clouds induced to form sooner, or last longer, or grow denser and deeper.

b. Natural fog induced to last longer.

c. Natural precipitation induced to increase locally at other times.

d. Thunderstorm activity induced to either increase or decrease, depending on the nature of the atmosphere.

Our understanding of the natural process of condensation and precipitation is far from complete.[39] Therefore the extent to which a cooling tower affects the above processes cannot be reliably estimated from a theoretical standpoint. However, actual observations show that increases in local cloudiness are common in some areas. Changes in precipitation were small and much less frequent. Additionally, no reports of thunderstorm modifications are known to date. Further elaboration on the above four items was given within the report[39] but, again, only from a qualitative viewpoint.

Tower blowdown is returned to Lake Erie at the shoreline. The blowdown's temperature excess is expected to range between 12 and 23°F. The maximum heat discharged in this manner is expected to be less than 0.78×10^8 Btu/hr, or 1.5% of the once-through requirement. The returned water will have roughly three times the concentration of dissolved solids (500 ppm) than appear locally in the lake. Additionally, free chlorine will be present in concentrations estimated to be less than 0.1 ppm.

It is estimated that a maximum total of 19,500 gpm will be evaporated and lost by drift from the towers and a small pond used in the closed cooling system. Drift from both towers is expected to be less than a maximum of 0.1% of the tower circulating flow. By assuming the 0.1% figure, together with a solids-concentration factor of three, the investigators estimated that the dissolved solids emitted to the atmosphere would be less than 5300 lb per day.

3. Zion Station

Several recent studies have investigated closed-cycle cooling systems for nuclear power plants along Lake Michigan. The first such study was that of the Sierra Research Corporation in which evaluations were made to determine the possible environmental impact of operating the 2200-MWe Zion Nuclear Generating Station with evaporative cooling towers.[26] Several cooling-tower configurations were considered for the Zion site: 70 mechanical-draft tower cells, each 60 ft high, 70 ft wide, and 40 ft deep; 10 combination mechanical-natural-draft towers 250 ft high and 300 ft in diameter; five natural-draft towers, 350 ft high and about 300 ft in diameter; and three natural draft towers 500 ft high and about 500 ft in diameter.

Basically, the calculations made for fog frequencies required the input of tower design parameters together with historical meteorological data for the Zion site. Since the requisite meteorological data were not available for the Zion site, recourse was made to U.S. Weather Bureau data, gathered at the Chicago (Midway) and Milwaukee airports, which provided tabulations of the frequency of various combinations of temperature, humidity, and wind speed. Atmospheric stability and wind assessments required for the tower fog calculations were obtained from determinations made by the NUS corporation for the Zion plant in relation to radiological dispersion issues.

The results show that ground fog, as a result of mechanical-draft tower operation, could be expected somewhere around the plant (which may include Lake Michigan as well) a maximum of 650 hr/yr. It was stated that a ±20% variation in this number could be expected in any given year due to natural variability. The maximum frequency at any one point was calculated to be 90 hr/yr at 1.5-2.5 miles north of the plant using Milwaukee meteorological data. Chicago meteorological data also show a maximum frequency in that location but only 50 hr/yr. Using either the Chicago or Milwaukee data, the investigators predicted that fogging would most likely occur from northwest through the north and easterly directions. Predicted fog frequency is least to the west of Zion station. Fog-frequency estimates as a result of tower operation for various towns or locations were given as: Waukegan Airport, 20-40 hr/yr; the town of Zion, about 25 hr/yr; Waukegan, 18 hr/yr; Winthrop Harbor and along highways northwest of the site, 40-60 hr/yr; and the lake shore 1-2 miles north of the plant, 50-90 hr/yr.

Most occurrences of fog would be between 0 and 34°F. The winter months, December, January, February, and March, show the highest fog frequency; June, July, and August the least. The most favorable hours for fog formation are from 3 to 7 A.M. The greatest majority of all cooling-tower fogs should be observed between 12 midnight and 10 A.M. Most fogging episodes were said to be short-lived, with a duration of 2-4 hr. Very few situations are expected with a persistence over 6 hr. A fog duration of [illegible] to 12 hr or more could infrequently occur when the tower fog mixes with natural fog. The report concludes that if an average duration of 3 hr is assumed for a fogging episode as a result of tower operation, then the mechanical-draft towers would produce ground fog on a maximum of 25 days/yr at any one point.

The fog frequencies computed for the taller towers were considerably lower, decreasing with tower height. For the 500-ft-tall towers, estimated ground fog frequencies ranged from 5-40 hr/yr the distance of maximum frequency being 12.4 miles from the site. Ground-fog frequencies for the 350-ft towers were estimated to occur between 15 and 75 hr/yr, 9.31 miles being the distance of maximum frequency. Fog frequencies for the 250-ft tower were 25-100 hr/yr, the distance of maximum frequency being 7.4 miles. With fog persistence of 2-4 hr, individual fog episodes were expected to occur 5-30 days/yr with these taller towers. The predicted ground-fog frequencies are significantly lower with increasing tower height, and when fog does occur it generally occurs further from the plant with increasing height. However, because ground-fog frequencies are less with the taller towers, this does not imply that the tower plumes will dissipate close to towers. Rather, plumes from the towers will frequently persist for distances as great as 10-20 miles, but only rarely will these plumes contact the ground. The distribution of fog from these taller towers with respect to the time of the day, the month, and the direction were stated to be similar to the mechanical-draft situation.

A summary chapter in the Sierra Report was devoted to interpreting the results. Although the physics of the problem formulation is based on accepted and understood models, these models nevertheless have never been verified against long-term tower tests and should therefore be interpreted as state-of-the-art estimates. It was estimated that the calculated values should be correct to within ±25%, at a confidence level of 95%.

Natural fog at Milwaukee and Chicago (Midway) averages 260 and 160 hr/yr, respectively. It was estimated that about 35% of the tower-fog cases would coincide with measurable natural fog. When fogs occur together, the fog density would naturally be greater in the tower plume. In general, the intensity of the fog at the ground under such situations should produce visibilities in range of 200-1000 ft, that of dense natural fog.

Since most tower fogs would occur when temperatures are below freezing, some icing was anticipated whenever the supercooled fog made contact with solid objects at the ambient temperature. But, because fog situations will seldom last longer than several hours, heavy icing of the kind that would endanger vegetation or structures would not be expected. The report cautioned, however, that any icing on highways could be a serious hazard.

The Sierra report mentioned that under certain wind conditions downwash and aerodynamic distortion, not only from the towers themselves but also from nearby plant building structures, could to a small extent increase the frequency of ground fog. The number of such incidents would decrease with increasing tower height. Such effects could be minimized with the 500-ft towers.

The Environmental Report[26] summarized additional problems that could result from cooling-tower operation. Since the Waukegan airport is about 3.25 miles away, it was suggested that both the vapor plumes and tall towers, if used, could represent aircraft hazards. It was further suggested that the water evaporated by the towers (66 cfs) might legally be construed as a Chicago area water diversion and hence apply against the 3200 cfs internationally allocated for the Illinois-Lake Michigan diversion. The report additionally pointed to the undesirable aesthetic impact of either the resultant tower plumes or the towers themselves, particularly the taller ones. Tower blowdown and drift problems were not pointed to as being significantly consequential. The blowdown thermal-discharge rate to the lake would be roughly 0.96 x 10^8 Btu/hr, compared to 150 x 10^8 Btu/hr for once-through cooling.

Several other alternative closed-cycle cooling systems were investigated for the Zion station: a 3000-acre cooling pond, a 300-acre spray pond, and dry cooling towers. The 3000-acre pond was ruled out because land use in the area precluded everything except a possible location several miles west of the site. Because of elevation changes and distances involved, the pumping-energy requirements of this alternative would reduce the capability of the station more than any other evaporative-type alternative. In addition, the pond site would require a number of residences and farms to be displaced. The 300-acre spray-pond alternative was rejected, partially because of available land limitations and partially because potentially severe fogging and icing problems were anticipated. The dry cooling towers were rejected as being viable alternatives, primarily because of excessive costs.

The Illinois State Water Survey published a document summarizing their findings concerning the potential effects of cooling-tower effluents on the atmosphere with emphasis on the Zion Plant.[62] A literature search was made covering basically three topical areas: fog and icing, clouds and precipitation, and severe weather. More attention had been given in the literature to fog and icing problems associated with tower effluents than any other potential weather effects. The report stated that, "The majority opinion appears to be that fog and icing are usually minor problems with natural-draft towers employing evaporative cooling, since these towers usually extend to heights of 350 ft or more into the atmosphere so that the plume seldom, if ever, sinks to ground level. Mechanical-type towers release their effluent at a much lower level (50-75 ft) and in a much more turbulent condition due to fan-forced ejection, so that there appears to be a high probability of tower-induced fog and icing at or near the ground on occasions. However, the frequency of such occurrences cannot be assessed accurately with existing observational data."[62]

Very little quantitative data on the effects of cooling towers on clouds and precipitation could be found. The report stated, "Occasional observations of light drizzle or snow attributed to tower effluents have been reported. Also, there have been several reports of tower plume contributing to cloud formation downwind; apparently, these are usually stratus-type clouds and observations of cumulus developments have been rare. A few mathematical calculations have been made to determine the cloud and precipitation producing potential of cooling tower plumes, but no meteorologically acceptable analyses have been made to assess quantitatively the possibility that these plumes augment precipitation and cloud systems associated with naturally occurring storms."[62]

The literature provided little information on any observed or calculated effects of towers on severe weather. The report concluded, "From consideration of atmospheric physics and dynamics, one would expect that any severe weather event resulting from cooling tower effluents would be attained only through a triggering or stimulation effect." In another paragraph the report went on to state, "In general, we conclude from available information in the literature that a very distinct void exists in our knowledge of the effects of cooling tower plumes on clouds and precipitation, with regard to both initiation and stimulation of these weather events. From climatological observations and cloud physics research, it is known that cumulus clouds and rain showers or thunderstorms can be triggered by small inputs of energy. Consequently, it is extremely important that research be initiated to combine existing knowledge of plume and cloud properties into mathematical models that will provide reliable quantitative estimates of the plume effect on downwind clouds and rainfall."[62]

The report summarized several specific findings related to Zion itself. Calculations showed that the amount of moisture that could be added to the atmosphere from Zion would be very small compared to natural fluxes in storm clouds. However, the addition of tower effluents could occasionally result in additional precipitation and possibly other undesirable intensification of naturally occurring weather events.

The meteorological effects from the interaction between cooling-tower effluents and lake breezes in the Zion area were stated to "likely result in additional snowfall under certain synoptic weather conditions." The analyses indicated that in spring "there would be days where a cooling tower plume would thicken on existing naturally occurring fog, but most of the time this fog would not persist more than 1 to 2 miles inland. Only very occasionally would a weather situation exist in which convective storms could be intensified by the lake breeze-tower plume interaction. Again, the general conclusion must be that accumulated knowledge is insufficient at this time to define in quantitative terms the effects of the interaction of cooling tower plumes with a lake-influenced atmosphere."[62]

A numerical model was used to estimate the amount of additional rain or snow, under steady light rain or snow conditions, that would result from tower operation at Zion. The results showed that the tower plume could lead to a small rainfall (trace amounts) within a few thousand feet of the tower. The additional rainfall amounts were said to be trivial, a fraction of 1% annually. Predictions on snowfall indicated that the total annual snowfall would be increased 1-2 in. within this lake-effect zone. There were also some indications using the model that the tower plumes could trigger a thunderstorm under special weather conditions.

Under a section titled, "General Conclusions and Recommendations" the report stated, "At this time meteorologists have not acquired adequate information to define in quantitative terms the meteorological consequences of the large amounts of heat energy and water vapor that are released into the atmosphere from cooling towers associated with nuclear power plants. The interaction between tower effluent and the atmosphere is very complex and dependent upon local conditions of climate and topography. ... . Although it was not the purpose of this report to compare the meteorological consequences of lake and atmospheric dissipation of waste heat, the authors consider it appropriate at this point to present several relevant facts pertaining to this problem. First, it is much more difficult to establish the meteorological consequences of atmospheric dissipation of waste heat from large nuclear power plants than it is to evaluate the meteorological ramifications of once-through cooling on Lake Michigan. This is because in both time and space the lake is much more stable with respect to its meteorological properties. ... . Secondly, the lake cooling spreads out the heat dissipation over a much longer time period than cooling towers and, therefore, localized effects on the weather are likely to be less pronounced with lake cooling than with cooling towers. Strictly from the meteorological standpoint, it appears that environmental effects are likely to be no greater, and probably smaller, with dissipation of waste heat into Lake Michigan compared with atmospheric release from cooling towers."[62]

4. Point Beach Station

Alternate closed-cycle cooling systems were investigated for potential use at the 1046-MWe Point Beach nuclear station in Wisconsin.[129] It was estimated than an 850-acre pond would be required for this purpose. The most significant environmental impact of this alternative was stated to be the elimination of land resources that presently support agricultural activities and small-game shelters.

With evaporative cooling towers, it was recognized that natural-draft tower plumes seldom return to the ground; thus the occurrence of ground-level fog or icing would be negligible. Some enhancement of cloud formation and precipitation was suggested. Two natural-draft towers, each 370 ft high and 400 ft in diameter, were contemplated for the Plant. With the natural-draft towers, it was stated that there would be a significant objectionable aesthetic impact. The towers would be three times the height of the tallest existing structures. With mechanical-draft towers the occurrence of fog would be more frequent. Four tower assemblies, each 73 ft wide, 60 ft high, and 360 ft long, were considered.

The report[129] indicates that the normally observed ground fogs are quite thin near the lake and suggests that the fogs created by mechanical-draft towers would probably extend from the ground to the tops of the towers and for a considerable distance downwind of the towers.

Conditions favoring this occurrence "would be limited mixing or inversion breakup (fumigation)." Whenever onshore breezes were present, there would be the likelihood that some of the moisture from the towers "could settle on forests and crop lands. When ambient temperatures are low enough, the moisture could freeze on tree limbs and lower story vegetation and could affect the wildlife cover." It was also indicated that "there would undoubtedly be some effect on seasonal crop characteristics due to increased moisture." The environmental impact for the alternative cooling systems is contrasted against once-through cooling in Table 6.[129]

In the Point Beach Environmental Statement,[121] it was estimated that a visible tower plume would be seen during much of the year: at least 50% of the year for mechanical draft towers and 95% of the year for natural-draft towers. Most of the plumes would occur close to the facility. However, under restrictive conditions the plumes could extend downwind as far as 30-40 miles for the natural-draft towers and as far as 15-20 miles for the mechanical-draft towers. Although the actual size of the plume and the distance it persists depend on meteorological factors, the plume will roughly be cigar-shaped and, under restrictive conditions, would have a maximum width of about 2 miles and maximum depth of about 1000 ft. Further, it was anticipated that cooling towers would increase the amount of fog at a particular point on the order of 1-11 and 5-75 hr/yr at the point of maximum effect for natural and mechanical draft towers, respectively.

Ground-fog calculations for the alternative 850-acre cooling pond indicated that ground plumes would extend from the pond to 1, 5, and 10 miles on the order of 45, 30, and 5 hr/yr, respectively.[121] The maximum number of hours per year of fog due to the cooling pond at any point at 1, 5, and 10 miles is estimated to be 8, 5, and less than 1 hr/yr, respectively. Pond fogging will occur almost exclusively in the winter, and the incremental environmental impact in terms of contributing to reduced visibility and icing should be inconsequential in relation to the occurrence of natural fog.

A spray canal system was additionally investigated. The plant would require a 30-acre canal with about 140 spray modules. A crude analysis was performed which indicated that potential fogging and icing resulted in occurrences of approximately 150, 80, 20, 4 hr/yr at 1/2, 1, 5, and 10 miles from the canal, respectively.[121]

5. Kewaunee Plant

Several closed-cycle alternative cooling systems were investigated in relationship to the 540-MWe Kewaunee Plant in Wisconsin.[130] A single 450-ft-high, 480-ft-dia, natural-draft evaporative tower and three parallel banks of mechanical-draft towers, each bank 50 by 350 ft, were proposed as alternatives to once-through cooling. In a Westinghouse study concerning evaporative towers for the Kewaunee site, the potential

Table 6

Summary of Alternative Cooling Decision Factors[129]

	Once Through	Mechanical Draft Towers	Natural Draft Towers	Cooling Pond
ECONOMIC COST	. . .	Additional $45,350,800	Additional $56,449,400	Additional $49,759,800
FUNCTIONAL DESCRIPTION	*Construction 100% complete	*Construction not started	*Construction not started	*Construction not started
	*Open system	*Essentially closed system	*Essentially closed system	*Essentially closed system
	*Intake structure, pumps and two discharge flumes	*(4) units 360' x 73' x 60' south of plant	*(2) units 370' high by 400' diameter ea.	*850 acre pond
	*Thermal releases in Lake Michigan >40°, maximum increase=19.3°F <40°, maximum increase=31.5°F	*Thermal releases to atmosphere	*Thermal releases to atmosphere	*Thermal releases to cooling pond
ENVIRONMENTAL IMPACT				
Land Use				
Area Used	*None	*20 acres for towers	*20 acres for towers	*850 acres for pond (maximum size possible
Recreation	*Probable better fishery due to thermal attraction	*Negligible impact	*Negligible impact	*Possible public fishing and other use of pond
	*Low profile	*Moderate impact due to structures and plumes	*Large impact - structures and plumes would dominate landscape	*Mixed impact - attractive water-body, long high dike
	*Silent	*Fan noise	*Silent	*Silent
	*Probable attraction for water-fowl	*	*	*Possible attraction for waterfowl
	*Educational & conservation facilities possible	. . . .	*	*Some potential
Water Use	*Least consumptive use of water	*High consumptive use of water	*High consumptive use of water	*Possible impact on groundwater High consumptive use
Heat Dissipation				
Fog and Icing	*Little impact	*Some increase in incidence of fog and icing/wetting of State Highway 42 and switchyards	*Some local icing due to drift	*Some increase in ground fog potential influencing State Highway 42
	*	*Low level plumes visible in vicinity	*High level plumes visible in region	* . . . .
	*	*High possibility of plume touchdown	*Possibility of plume touchdown	* . . . .
Standards	*Meets existing state criteria	*Would meet all thermal criteria	*Would meet all thermal criteria	*Would meet all thermal criteria
BIOLOGICAL IMPACT				
Aquatic	*Little impact on Lake Michigan but more studies being conducted	*Negligible impact	*Negligible impact	*Negligible impact
	*Chemicals not presently required	*Blowdown chemicals returned to lake	*Blowdown chemicals returned to lake	*Some blowdown chemicals to lake
Terrestrial	*Minimum impact already sustained	*Possible effect to local vegetation from drift salts and icing	*Possible effect to local vegetation from drift salts and icing	*Portions of forest habitat replaced by lake
CONSTRUCTION IMPACT	*Moderate impact, already sustained	*Additional impact to terrestrial ecosystem	*Additional impact to terrestrial ecosystem	*Large impact to terrestrial ecosystem
USE OF RESOURCE	*Minimum use	*About 7% increase in fuel	*About 8% increase in fuel	*About 9% increase in fuel

environmental impact of such towers was discussed and most of the following material on towers have been abstracted from this report.[124]

The meteorological effects of evaporative towers were considered. Icing and fogging could occur and cause problems on nearby roads or in the plant's electrical switchyard about 10 days annually. This did not count the number of times the tower plumes might influence natural fogging or icing conditions by making them more severe or of longer duration in the vicinity. Cooling-tower drift problems were discussed and implied to be of minimal consequence offsite. Except for certain tower chemicals, "Watering lawns in residential areas with average city water would result in as much or more dissolved solids deposit as would drift from cooling towers using Lake Michigan water." Drift was calculated to add roughly 400 lb of dissolved solids per year in the plant vicinity.

Blowdown, while singled out as an environmental issue, was only discussed briefly by noting that it contains not only increased concentrations of dissolved solids, but also some chemicals.

The Westinghouse report additionally provided a quantitative evaluation of the potential biological impact of cooling towers as contrasted against once-through cooling for the Kewaunee Plant. Through a series of rather simple calculations and arguments, it was shown, based on conservatively assumed population, fractional capture, and mortality estimates, that a maximum fish kill of 7650 lb/yr can be expected with once-through cooling. Closed-cycle tower cooling was stated to result in zero fish kill. The fish-kill equivalent of plankton mortality (including meroplankton) resulting from plant operation was also calculated using estimated values of lake plankton biomass, cooling-system flow rates, fractional losses in the condenser and in the towers and plumes, and a two-to-one fish-to-plankton-kill biomass ratio. The estimated maximum values of fish kill due to once-through and closed-cycle cooling were 2900 and 236 lb/yr, respectively. The net estimated overall fish and fish-equivalent kill range was stated to be 1680-10,550 lb for once-through cooling and 120-270 lb for closed-cycle cooling. 10,550 lb/yr represents an average of 30 lb/day. A calculation was made to show that the increased fuel-energy cost alone, resulting from closed-cycle tower operation versus once-through cooling, amounts to $600,000/yr. This figure corresponds to a biological cost of 10,550 minus 270 or 10,280 lb of fish per year, or about $60/lb. This figure was then compared to the cost of fish produced at a hatchery, $1.50/lb. The report concluded that, "The great disparity in the cost per pound of fish suggests that better commitment of total resources could be made by building fish hatcheries instead of cooling towers." The environmental impact of various alternative cooling-tower schemes for the Kewaunee Plant is summarized in Table 7 as abstracted from the Westinghouse Report.

Table 7

Environmental Impact of Various Cooling Modes[124]

Area of Impact	Parameter	Once-through	Closed-Cycle Cooling Towers
Fish	Flow Rate, GPM	413,000	28,000
	Air Screen Effectiveness, %	0-50[1]	0-50[1]
	Fish Capture at intake, %	0.34	0.0017
	Fish Transport Mortality, %	100	100
	Estimated Annual Damage, lb/year	2300-7650	1-32
Plankton	Condenser Mortality, %	10-20	10-20
	Cooling Tower Mortality, %	0	100
	Plume Mortality, %	10-20[1]	4-8
	Meroplankton Mortality, lb/year	725-1450	59-118
	Estimated Equivalent Fish Damage lb/year	1450-2900	118-236
Fuel Resource	Heat Rate Btu/Kw-HR	10,440	11,070
	Fuel Penalty for Towers, %	0	6
Effluents to Air and Land	Fog Persistence Due to Towers, Days/year	0	10
	Drift, GPM	0	400
	Salt Fallout, lb/acre/year	0	400
Effluents to Water (Plume)	Chemical Release	Nil	Nil
	Radionuclide Release, pCi/l[2]	5	89
	Thermal Plume:		
	Discharge Temperature Above Ambient, °F	20	20
	Acres Affected at +1°	2720	141
	Acres Affected at +4°	252	72
	Acres Affected at +10°	7	28
	Acres Affected at +18°	0.7	4

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[1] These values are assumed or estimated based on scant data; values should be verified by field or laboratory work.

[2] 10CFR-20 Limit = 100 pCi/l
10CRF-50 Limit = 20 pCi/l

A cooling-pond alternative, between 650 and 1500 acres, was investigated for the Kewaunee Plant.[130] The most significant environmental impact of the pond would be the removal of 650-1500 acres of crop and pasture land. A spray canal was also considered for the plant. No particular environmental impacts were cited for the spray canal other than suggesting that fish damage similar to that of cooling towers can be expected as a result of blowdown to the lake.

6. Bailly Station

An evaporative natural-draft cooling tower will be used at the Bailly Generating Station in Indiana for its 685-MWe nuclear unit.[91] Two possible adverse meteorological effects resulting from tower operation were cited: fog and drift. Calculations for the southern end of Lake Michigan indicated, "relative humidity and temperature combine in such a manner that there is a high probability of producing fog from a cooling tower only 0.11% of the time (0.4 days per year)." The probability for ground fog from a natural-draft tower was stated to be even lower.

Three atmospheric conditions were discussed that could conceivably limit the plume rise from a tower and thereby increase the potential for contributing to natural fog: a strong atmospheric temperature inversion, the presence of a high wind, and tower downwash. The report considers none of these three to be credible mechanisms for contributing to natural fog. Two types of atmospheric temperature inversions--a surface-based radiation inversion and a subsidence inversion--were also considered as potential mechanisms for causing a plume to be trapped at low levels and thereby possibly contributing to existing natural ground fogs. These were subjected to qualitative arguments, and it was concluded that the tower plume would very likely penetrate the radiation inversion or rise to a sufficient height in a subsidence inversion (~1000 ft) insuring that a natural-draft tower plume would not likely play a contributing role in existing ground fog. In citing reference material within the report, the investigators stated that, "Surveys of operating cooling towers in the United States and in Europe confirm that natural draft cooling towers do not cause or intensify ground fogging conditions."[91]

Drift and evaporative losses from the Bailly tower are estimated to be about 7100 gpm or 15.6 cfs. This quantity was stated to represent only about 0.04% of Lake Michigan's natural evaporative losses over the entire lake. It was therefore assumed that the Bailly tower losses will have no significant impact on the lake.

Tower blowdown was not expected to be a problem since most of the impurities in the blowdown water will be the same as those in the lake. Some chemical treatment of this water, mainly in the form of sulfuric acid and chlorine (hypochlorite ions), is anticipated. The investigators, however, estimated this to be of such low concentrations when discharged that no adverse effect on the lake is expected.

The possible synergistic effects resulting from the combination of the cooling-tower plume with existing atmospheric constituents were discussed. It was felt that since no such adverse effect has been documented at other natural-draft cooling-tower installations and since the regional air-pollution indices are stable or declining, this would not be a problem. Consideration was also given to the possible effects associated with the tower plume blending with the stack effluents from the operating fossil-fired units at the Bailly site. The speculation is that sulfur dioxide in the stack effluents could be oxidized and then combined with the tower vapor to form an acid mist. The statement was made that since other larger coal-fired plants with natural draft towers have not reported any adverse effects, no problem is anticipated at Bailly. Further arguments were developed stating that the oxidization of sulfur dioxide in a combined plume could be catalized by certain fly-ash constituents. Since the Bailly fossil units remove 99% of the fly ash through electrostatic precipitators, it was inferred that this would reduce the probability of acid mist.

Mechanical-draft cooling towers were also considered as an alternative to natural-draft towers. Land-area requirements for the mechanical towers were estimated to be roughly 23 acres, as opposed to 4.5 acres for natural-draft towers. This excess land area for the "economical arrangement" of mechanical-draft towers at the Bailly site is not available; therefore this alternative was rejected. From an environmental point of view, mechanical-draft towers were noted to have a greater probability of producing ground fog than natural-draft towers. Since the Bailly site is located in an industrial area near a highway, this potential problem could be significant. It was stated that mechanical-draft towers are best suited for areas where fog is unlikely or in sparsely settled areas.

Cooling ponds, spray ponds, and cooling canals were noted as having a potential for producing ground fog and for evaporating more water than cooling towers. They were primarily rejected as alternatives because of limited land availability. Dry cooling towers were also mentioned as an alternative. They were rejected, however, because their use would significantly decrease the plant efficiency unless special turbines could be made available. The requisite turbines could not be fabricated in time to meet the unit's operating date. The towers were additionally rejected because there was some doubt whether a dry-tower system could be physically incorporated into the Bailly site because of its anticipated size.

Once-through cooling was also considered for the new Bailly unit with either a shoreline or offshore discharge. It was indicated that a detailed cost-benefit analysis would probably show this option to be the best choice. It was rejected as a viable alternative since it was believed that once-through cooling might be prohibited on Lake Michigan in accordance with the recommendations of the Third Lake Michigan Enforcement Conference. The utility stated that even though no existing law prohibits once-through cooling, it could ill afford an operating-license delay of well over one year as recently experienced by the Palisades Plant and then end up installing duplicate facilities.

7. D. C. Cook Plant

The environmental report for the 2200-MWe Donald C. Cook Nuclear Plant[65] outlines four alternative cooling systems which could be used to backfit the present once-through system. It was estimated that a cooling pond would have to be at least 5000 acres and have a minimum depth of 8-12 ft. This alternative was considered totally impractical, since land acquisitions of the required area are not readily or realistically available in the surrounding scenic dunes area. The sandy soil in the general area would not be suitable to retain water without the costly installation of asphalt or some comparable material. The pond was estimated to consume roughly 40,000 gpm of lake water, three-quarters of it through evaporation and the remainder through seepage losses. Aesthetically the pond would be the most desirable of the alternatives considered. From an ecological point of view, there would be no significant effect other than those anticipated from the displacement of farm and recreational land.

Two natural-draft evaporative towers, each 500 ft high and 520 ft in diameter, were considered as another alternative. The towers would consume about 30,000 gpm of water. The meteorological effects resulting from the discharge of this quantity of water vapor from two localized points 500 ft above the ground were said to be unknown. Under certain atmospheric circumstances the plumes could cause fogging and contribute to icing conditions in the winter. The report states that this alternative would constitute a significant aesthetic intrusion along the scenic shoreline and would completely destroy the low-profile Cook Plant design. During cold weather the vapor plume would be visible several thousand feet in the air, again an aesthetic cost. From a land-use point of view the two towers would require the leveling of 40 acres of presently undisturbed dune land.

Fourteen mechanical-draft towers, each 73 ft wide, 400 ft long, and 60 ft high, were considered for the Cook Plant as another alternative. The mechanical-draft system would consume about 30,000 gpm of lake water when in operation. The system would also require some 90 acres of dune land for installation. One of the major disadvantages of a mechanical-draft-tower system is discharging the water vapor and droplets at a relatively low altitude above ground; this could result in serious icing problems on plant-access roads and on public highways. Since mechanical towers have such a low profile, they would not detract from the plant's low profile. However, because of their bulk, they might have a significant adverse effect upon the plant's appearance from the lake. Ecological effects on the lake from blowdown discharges from either the mechanical- or natural-draft towers were thought to be insignificant.

Dry cooling towers were discussed, but they were not considered a viable alternative for a plant the size of Cook. The report indicated that even if they were feasible they could not be used at the Cook Plant because the steam turbines presently installed could not operate with them.

8. Palisades Station

The Environmental Statement for the 715-MWe Palisades Nuclear Generating Station[119] discusses several closed-cycle cooling alternatives to the plant's presently used once-through system. (The plant will be backfitted by November 1973 with mechanical-draft towers as part of a settlement with interveners at a licensing hearing.) The closed-cycle cooling alternatives considered were mechanical- and natural-draft evaporative towers, dry towers, and cooling and spray ponds. One of the principal impacts of the evaporative towers was considered to be the addition of chemicals to the lake via blowdown and the addition of chemicals and water to the surrounding land as a result of drift. (The blowdown issue is discussed in more detail in Section VI of this report and will not be covered here.) The Environmental Statement concluded that once-through cooling, with appropriate modifications to the present facility, would cause less of an impact on the lake than that resulting from the Palisades Plant operating with cooling towers.

The report mentioned several advantages of natural-draft towers over mechanical-draft systems: reduced requirement for corrosion inhibitors, less drift, and a long-term monetary cost advantage. The disadvantages of a natural-draft tower for the Palisades location were thought to be the aesthetic impact of a 400-ft-high structure on the naturally scenic sand dunes and the possibility that a tall tower would disperse fog and drift and cause icing over a wide area beyond the plant site. There was a greater possibility for the plume from a tall tower to affect traffic on nearby highways; plumes from a mechanical-draft system would be expected to primarily affect onsite areas. Dry cooling towers were dismissed as a viable alternative for the Palisades Plant primarily because the existing turbine and condenser system could not accept backfitting without a rather severe penalty in plant operating efficiency and further the state of the art on dry towers is still in its infancy for an installation the size of the Palisades Plant. Cooling and spray ponds were also considered as alternatives. The cooling pond would require a minimum of 1000 acres, and building the pond in the immediate plant vicinity would require the destruction of the scenic sand dunes. The possibility of building a pond about a mile inland was also considered; however, this alternative would have meant destroying 1000 or more acres of agriculturally productive land. These were felt to be unacceptable alternatives by the utility. The spray pond was rejected because its reliability was thought to be too variable under changing meteorological conditions. The loss of 30 acres of dune land required for the pond, the great possibility of local icing during winter operation, unknown drift problems, and the possibility of fogging under adverse humidity conditions were significant adverse effects making the spray pond an undesirable alternative.

NUS Corporation evaluated the potential environmental impact of operating the Palisades Plant with either a 490-ft-high, 485-ft-base-dia, natural-draft tower or two 50-ft-wide, 470-ft-long, 62-ft-high, mechanical-draft towers.[33] Requisite meteorological data for the Palisade's site were obtained from Muskegon County Airport, located about 70 miles north of the site. The meteorological data were analyzed to determine under what conditions evaporative towers could produce or intensify local fog conditions.

Natural fog frequencies were correlated against the time of day, the month of the year, atmospheric stability, wind speed, cloud cover, and the relative humidity defect (defined as the difference between saturated relative humidity and the ambient relative humidity). Fog conditions are dependent on wind direction and more likely to occur for winds from the east through southwest directions. Also fog is more likely to occur under neutral and stable atmospheric conditions, particularly between 10:00 P.M. and 9:00 A.M., and is most often observed with some cloud cover. The relative humidity defect was the single parameter of greatest importance in fog formation. For defect values approaching zero, there was a 90% or greater probability that fog conditions were observed. The report stated, however, that fogs do exist and can form under conditions when the relative humidity defect is different from zero, that is, when the atmosphere is unsaturated. It was determined that the probability of fog formation could be adequately represented by a single relationship with the relative humidity defect.

Calculations were performed that yielded estimates of visible plume persistence, the possibility for induced fogging and icing, and potential downwash events. With regard to the persistence of a visible plume, it was felt that the phenomenon represents only an aesthetic problem.

The proposed mechanical-draft facility was found to have a lower incidence of long plume lengths. About 45% of the visible plumes were calculated to be dissipated within 350 ft of the towers. Visible plume lengths longer than 2 miles were estimated to occur for five of the total hours of the year.

For the proposed natural-draft tower, visible plumes longer than 2 miles were estimated to occur as frequently as 44% of the total hours of the year, 65% of these hours occurring during the winter season. In terms of the aesthetic effects of the visible plume, the areas of greatest potential concern were the communities of Covert and South Haven. The estimated percentage of the time the visible plume was calculated to pass over these towns was presented in tabular form in the NUS report.[33] For Covert, conditions favoring the downwash of tower plumes over the nearest major highway I-196 were investigated. The frequency of such possible occurrences for the natural-draft tower were estimated at 2 hr of fogging and 0.2 hr of icing during the spring, 0.3 hr of fogging during the fall, and 2.7 hr of fogging and 2.2 hr of icing during the winter. These calculations were stated to be upper limits because observations of actual cooling-tower installations have not confirmed such downwash phenomena. The report indicated that mechanical-tower operation under conditions favoring downwash would not affect highway I-196 but only roads and structures on the plant site.

The probability of induced fogging, calculated for the mechanical-draft tower, indicated an increase of natural-fog duration a maximum of 14 hr/yr, 6.25 miles northeast of the site. This was the maximum value in any direction. There are 798 hr of fog occurring naturally in the vicinity; the median duration of each fog episode is 2 hr. An increase of 14 hr of duration was then compared with the average fog beginning 1 min earlier and lasting 1 min longer. This was thought not to be a significant overall change. The natural-draft tower was found not to induce ground-level fog. The probability of induced icing was examined. The results showed similar percentages to increased fog probabilities and therefore were not considered a significant problem. Again the natural-draft-tower results indicated no increase.

Several recently published reports in the open literature contain information relevant to this survey. These are now considered.

9. Natural-draft-tower Operating Observations

A final report describing a cooling-tower field study at the 1800-MWe Keystone Generating Station in western Pennsylvania was published in January 1971.[113] The purpose of the study was to describe and evaluate the potential effects that emissions of water vapor and heat from 325-ft-high, natural-draft, evaporative-cooling towers have on the local environment and climate. During the period of field observations in September, November, and December 1969, when the Plant was operating at one-sixth of its design capacity, no adverse weather effects due to the operation of the facility were shown conclusively. Drift drizzle beneath the towers was not detected, nor was any increase in ground-level humidity underneath the plume path. Long-term pre- and posttower climatological data from nearby meteorological stations were studied, and only in one situation was a possibility of precipitation enhancement noted for the two-year period analyzed.

General observations had shown the visible tower plumes normally to rise to an altitude of about 650 ft and travel downwind another 650 ft before evaporating. During periods of high humidity and low temperatures (25-30°F), the plume was observed for thousands of feet downwind. Casual observations indicated infrequent cloud initiation during periods of otherwise clear skies. However, the tower plume would often merge with low stratus clouds. In addition, the tower plume mingles with the stack effluent from the fossil-fired generating units. Mixing of the two plumes was confirmed by the presence of acid droplets in the visible portion of the cooling-tower plume.

The report concluded that the full environmental effects of natural-draft towers could not be stated conclusively from the study because the actual field observations were intermittently made over one season only, the plant was not operating at or near full power, and field instrumentation was lacking in several essential areas.

Hosler[60] reported on a single fogging incident observed during two years of investigation at the Keystone Plant in which a plume reached the ground in the vicinity of the natural-draft towers. It was surmised that an inversion on this occasion was just at the proper height and strength to confine the plume and its vertical oscillations within the inversion. Photos taken from an aircraft on the same day and within several minutes of the Keystone ground-fog incident showed that the injection of water vapor and condensation nuclei by steel mills in the Pittsburgh area resulted in fog and a dense cloud extending a hundred miles downwind. The steel mills were apparently injecting their effluents at the same level as the surrounding terrain through many small-diameter sources. Hosler stated that had a power plant injected effluents at the same level, a similar result would have been expected.

Decker[37] has reported on the relative probability of evaporative cooling systems to produce sufficient ground fog to obstruct visibility. The results of his survey are given below in the order of increasing probability of surface fogging. This information was obtained from observational data.

Type of Cooling System	Probability of Obstructing Visibility
Tall, natural-draft towers, standing fully equipped with drift eliminators.	Extremely low, virtually zero.
Tall, natural-draft towers, alone but without drift eliminators.	Low, but likely to occur with high humidity and stagnation.
Tall, natural-draft towers, close to fossil-fueled smokestacks emitting acid-producing stack gases.	Low to substantial, depending on prevalence of wind direction and spacing of stack and tower(s).
Mechanical-draft towers emitting at low level.	Substantial, but highly variable depending upon wind and orientation or grouping of units.
Slack water, ponds, and lakes, and spray ponds.	Low to substantial, depending upon the stagnation of the atmosphere and confinement of humidified air.

Colbaugh et al.,[24] in an interim report, noted that there is a lack of quantitative information for the reliable assessment of the effects of cooling-tower plumes on the environment. For this reason, a comprehensive field investigation of natural-draft-tower plumes was initiated at the Tennessee Valley Authority's 2808-MWe coal-fired Paradise Power Plant in Kentucky. The plant has three natural-draft towers, each 436 ft high and 321 ft in diameter at the base. Tower circulating flow is 290,000 gpm. The towers are designed to reduce the cooling water to 72°F at yearly average atmospheric temperatures of 57.4°F dry bulb and 52.2°F wet bulb and a cooling range of 27.5°F.

General field observations of plume behavior were initiated in December 1969. A more comprehensive program began in January 1971 to collect, compile, and analyze plume configurations under various meteorological conditions. Preliminary results were presented for observations made during 130 days throughout the 1970 calendar year. These are shown in Table 8. The data show considerable monthly variation in plume length. Preliminary evaluation of more recently gathered data has revealed no significant adverse effect that can be attributed to tower operation. On one occasion, however, there was a measurable increase in the temperature and moisture content downwind of the visible plume, with mist being detected both under the visible plume and downward.

10. Drift Observations

Two recent documents have reported on drift measurements made on mechanical- and natural-draft towers using different experimental methods for drift determination. Reference 47 associated the commonly used drift emission rate of 0.2% of the tower circulating flow as possibly originating with early developmental tower studies and before efficient drift-eliminator designs were put into practice. Measurements made on a commercial mechanical-draft tower (fan diameter, 28 ft; circulation flow, 12,500 gpm; range, 23°F; approach, 7°F) indicated the tower to have a 0.005% drift rate. A more extensively studied mechanical-draft tower (fan diameter, 18 ft; circulation flow, 6050 gpm; range, 10°F; approach, 7°F) was investigated using a laser-scattering technique and an isokinetic-sampling technique. The laser-scattering technique yielded a drift rate of about 0.0055%; the isokinetic method gave about 0.0076%. A natural-draft hyperbolic-tower (no specifications were given) determination showed drift to be around 0.005% via isokinetic sampling. The laser-scattering method yielded drift percentages around 0.00012% for particles larger than 145 μm. The 0.005% drift rate was said to be best representative of state-of-the-art natural-draft towers.

In Ref. 75, isokinetic sampling was conducted on the Homer City natural-draft cooling tower. The tower is a counterflow design with a full circulating flow of 208,000 gpm. The tower is stated to be 389 ft high with a 276-ft-dia base. Measurements indicated the drift for the tower under full rated conditions to be 0.0025%.

Table 8

General Field Observation Data* - 1970

Cooling Tower Plumes

Paradise Power Plant[24]

Month	Number of Observation	Average Number of Cooling Towers Operating	Average Plume Length - mi	Maximum Plume Lengths - mi 1	2	3
Jan.	7	2	1.2	3.0	2.0	1.5
Feb.	11	1.6	3.4	9.9	9.9	6.0
Mar.	10	2	0.9	5.0	1.0	1.0
Apr.	4	2	0.2	.4	.2	.2
May	14	2.1	.2	.6	.6	.4
June	14	2.7	0.4	1.0	.7	.5
July	18	3	0.6	4.0	1.0	.6
Aug.	14	3	1.2	5.0	4.0	3.0
Sept.	18	2.9	0.3	1.0	.7	.6
Oct.	13	3	0.6	5.0	.5	.5
Nov.	-	-	-	-	-	-
Dec.	18	2.5	0.6	.5	.5	.4

*Observations made between 0700 and 0730 local time.

A guaranteed drift level of 0.002% has been used for two natural draft cooling towers recently sold to the Potomac Electric Power Company for its Chalk Point Station.[2]

11. Theoretical Predictions

Portman[97] has reported on an analytical study for analyzing the downwind extent of fog from a cooling-canal spray for a steady wind blowing perpendicular to the canal. His analysis was conservative in that it should overestimate the downwind extent of fog and the frequency of occurrence for a particular distance. The analysis showed that the plume extent downwind decreases with increases in air temperature, diffusion intensity, and wind-speed variation with height, and with decreases in air water-vapor content, canal temperature, canal length, and efficiency of vapor transfer to air at the canal.

The analysis was applied to an 800-ft canal at 55 and 75°F, these temperatures being representative of winter hot-water temperatures of a once-through and a closed-cycle cooling system, respectively. With the Detroit City Airport temperature-wind-humidity statistics, a spray canal in the Detroit area operating at 55°F all year would produce a fog at 1 mile distance less than 2.5% of the time. For a canal at 75°F, the value is less than 10%. It was emphasized that these estimates should be regarded as upper limits.

12. Feasibility

Dry natural-draft cooling towers each 394 ft high with a 357-ft-dia base are being operated in Razdan, Soviet Armenia.[1] The power plant consists of three 200-MWe units, each matched with a natural-draft dry tower. One tower has been in service since January 1971. Apparently, the success of the Razdan operation is leading to the development of hardware and dry natural-draft towers for 800- to 1200-MWe unit capacities.

B. Monetary Costs

To aid in evaluating the impact of the Lake Michigan thermal-discharge regulations proposed at the March 24, 1971, session of the Lake Michigan Enforcement Conference, federal representatives presented a summary outlining EPA's position concerning the status of existing facilities that would or would not have to consider alternative cooling schemes to be in compliance with the proposed regulations. However, little specific data were presented to permit an evaluation of the cost of implementating these regulations. This section summarizes available cost information as abstracted from recent documents.

The report entitled "Feasibility of Alternative Means of Cooling for Thermal Power Plants Near Lake Michigan," presented at the Lake Michigan Enforcement Conference in September 1970, discussed closed-cycle cooling systems and estimated the costs for using them. Tables 9 and 10[95] summarize these costs in terms of utility-rate increases to the average residential customer. These tables are based on the assumption of newly constructed 1000-MWe fossil and nuclear power plants and show the effects of low (Case I), normal (Case II), and high (Case III) values of the economic factors involved in the analysis. These two tables were not intended to demonstrate the costs associated with the backfitting of existing plants, but rather represent cost estimates for power plants originally designed to accommodate these alternatives.

The cost of backfitting cooling facilities was subsequently discussed by Mr. Tichenor at the recent Michigan,[84] Wisconsin,[125] and Indiana[63] state hearings. An Edison Electric institute report, referenced in his testimony, suggested that retrofitting an existing plant using evaporative towers would cost $10-12/kW. A Mr. Woodson[134] was cited as estimating the capital cost of converting an 800-MWe plant from once-through to closed-cycle cooling at about $3,000,000, or $3.8/kW. Mr. Warren, of the FPC, was cited[95] in estimating the cost of backfitting all of the 15,000 MWe of capacity existing and under construction on Lake Michigan as $150,000,000 or $10/kW. However, according to the testimony, none of the above estimates included the cost of reduced generating capacity, increased fuel costs, and increased operating and maintenance expenditures. According to the testimony, these items could add an additional $10-15/kW in equivalent capital investment to the initial capital investment. Adding these costs to the initial capital-cost values shows a range of backfitting costs of $14-27/kW. Given a plant load factor of 80% and a fixed charge rate of 14%, a $14-27/kW range is equivalent to an increase in busbar cost of about 0.3-0.6 mill/kW-hr.

Mr. Tichenor cited an American Electric Power Service Corporation estimate for backfitting the D. C. Cook Nuclear plant with natural-draft cooling towers. An initial capital investment of $32,000,000 or about $15/kW was quoted. The company estimated the summer capability loss to be 80 MWe. According to the testimony, if this capacity loss was made up with an equivalent amount of gas-turbine peaking units, the capability loss would require a capital investment of $8,000,000. Adding to this an equivalent investment of $5/kW for operation and maintenance and increased fuel expenses, the total backfitting capital cost was estimated to be $24/kW ($52,800,000 for the 2200-MWe plant). With an 80% load factor and a 14% fixed-charge rate, the increase in busbar cost was indicated to be approximately 0.5 mill/kW-hr.

Cost figures were cited for the Palisades Nuclear Power Plant to backfit with mechanical-draft towers and radioactive-emissions-control equipment: $15,000,000 in capital equipment, with $3,000,000 annually being required for the fixed charges on the capital, reduced efficiency, and increased operation and maintenance costs. With an assumed 80% load factor, $3,000,000/yr corresponds to a busbar cost of 0.6 mill/kW-hr.

Table 9

Increase In Busbar Cost Over Once-Through Design[95]

(Fossil Fueled Plants)

		Cost Increases (Mills/KW-HR)					
Case	(Mills/KW-HR)	Wet Mech. Draft	Wet Nat. Draft	Cooling Pond	Spray Canal	Dry Mech. Draft	Dry Nat. Draft
I	4.57	0.079	0.142	0.012	0.049	0.46	0.43
II	5.94	0.096	0.179	0.021	0.058	0.58	0.53
III	7.53	0.117	0.218	0.039	0.070	0.70	0.64

Economic Factors

Case	Plant Capital Cost ($/KW)	Fixed Charge Rate (%)	Fuel Cost (¢/10^6 Btu)	Land Cost ($/Acre)
I	110	11	25	250
II	135	14	30	500
III	160	17	35	1000

Table 10

Increase in Busbar Cost Over Once-Through Design[95]

(Nuclear Plants)

		Cost Increases (Mills/KW-HR)		
Case	Busbar Cost Once-Through (Mills/KW-HR)	Wet Mech. Draft	Wet Nat. Draft	Cooling Pond
I-N	4.37	0.085	0.138	0.021
II-N	5.83	0.108	0.177	0.033
III-N	7.60	0.135	0.219	0.061

Economic Factors

Case	Plant Capital Cost ($/KW)	Fixed Charge Rate (%)	Fuel Cost (¢/10^6 Btu)	Land Cost ($/Acre)
I-N	135	11	15	250
II-N	160	14	19	500
III-N	185	17	24	1000

Cost estimates were also presented for modifying existing discharge designs to conform with mixing zone limitations. Tennessee Valley Authority data on the 3450-MWe Browns Ferry plant indicated that a backfitted diffuser system would cost an additional $2,900,000 (roughly equivalent to 0.02 mill/kW-hr). Modifications to the once-through system for the 2600-MWe Cumberland Plant were estimated to cost $4,100,000 (about a 0.03 mill/kW-hr busbar cost equivalent).

Estimates for backfitting the 1047-MWe Waukegan and the 944-MWe State Line plants with modified discharges were given as $9,000,000 and $11,500,000, respectively.[20] With plant-load factors of 65% and a fixed-charge rate of 14%, the increase in busbar costs were calculated to be about 0.2 and 0.3 mill/kW-hr, respectively.

In summary, Mr. Tichenor's testimony given at the three state hearings concluded that:

1. For power plants initially designed to accommodate closed-cycle condenser cooling systems, the increase in busbar costs over once-through cooling is expected to be around 0.2 mill/kW-hr for an evaporative tower system (nominally a 1% residential rate increase).

2. The increased cost for backfitting with an evaporative tower system is estimated to be around 0.6 mill/kW-hr (nominally a 3% residential rate increase).

3. Increased costs due to modifying existing discharges range widely from 0.02 to 0.3 mill/kW-hr (nominally a 0.1-1.5% residential rate increase).

These busbar costs were related to the average residential consumer around Lake Michigan by assuming the consumer pays roughly 20 mill/kW-hr for his electrical power.

1. Pulliam Plant

Evan W. James, Wisconsin Public Service Corporation, stated at the Wisconsin hearings[125] that decreasing the heat content of the 392-MWe Pulliam plant discharge by 50% would cost some $3,770,000 in capital investment. Annual costs, including carrying this investment, operating costs, and maintenance costs, were stated to approximate $1,035,000 annually. If the plant went to a completely closed system rather than a tempering system, the above costs were stated to roughly double.

2. Kewaunee Plant

Backfitted mechanical-draft cooling towers at the 540-MWe Kawaunee Nuclear Plant were estimated by Mr. James to be $10,000,000 in construction costs.[125] Tower operation was stated to decrease the capacity of the plant by 7.1% and the efficiency by 3.8%. The cost of these towers in terms of investment, losses in plant performance, and operation and maintenance was stated to be about $3,650,000 annually. This revenue requirement expressed as an evaluated cost was given as $24,300,000.

The Kewaunee Environmental Report[130] listed additional cost figures for backfitted cooling schemes. For a single, natural-draft evaporative tower, the added construction costs for tower installation would be $16,902,000. Annual operating costs and capacity makeup were said to cost around $2,037,000 per year. The total additional annual cost for backfitting to a natural draft tower would then be $4,577,000 per year.

For mechanical-draft towers, backfitting costs were stated to be $10,118,000 in construction or, equivalently, $1,510,000 per year. Annual operating and maintenance costs, together with makeup of capacity, were said to be $2,105,000. Thus the total additional annual cost resulting from the backfitting of mechanical-draft towers is $3,615,000.

The costs that would result from backfitting with a cooling lake were estimated to be $18,068,000 in capital costs or, equivalently, $2,700,000 annual cost. Operating and maintenance and capacity makeup costs were given as $2,675,000 per year. The total incremental annual cost resulting from the backfitting of a cooling lake is thus given as $5,375,000 per year.

A spray-canal system was also investigated. The capital investment in such a system was estimated to be $11,410,000, or when converted to an annual cost, $1,710,000 per year for amortization and interest. Operating and maintenance costs, together with generating capacity makeup, were estimated to add an additional $2,208,000 per year. The total annual cost for a backfitted spray-canal system was given as $3,918,000.

3. Point Beach Plant

Testimony given at the Wisconsin hearings[125] by Mr. Patterson, Sargent and Lundy Consulting Engineers, estimated the construction costs of backfitting the 1046-MWe Point Beach Plant at $23,510,000 for a cooling lake, $22,936,000 for a mechanical-draft evaporative-tower system, and $31,797,000 for natural-draft evaporative towers. These costs reflect interest and estimated escalation charges and, in addition, land purchases for the cooling-lake alternative. With the costs for capability and efficiency-loss makeup and operating and maintenance expenses evaluated on a present-worth equivalent-investment basis, the evaluated cost of the cooling lake was estimated to be $49,759,800; the mechanical-draft tower system, $45,350,000; and the natural-draft towers, $56,493,400.

The Environmental Statement for the Point Beach Plant[121] provided additional information on the estimated yearly costs of backfitting the entire plant with alternative cooling systems: $7,600,000 per year for mechanical-draft towers, $9,500,000 per year for natural-draft towers, $9,100,000 per year for a spray-canal system, and $9,200,000 per year for a cooling lake.

4. Zion Station

The Environmental Report for the Zion Station[26] discusses the economic costs associated with backfitting the Plant with six alternative cooling schemes. The costs represent additional capital investments, capital-investment equivalents for loss of capability, and added operating costs to implement the particular alternative. For mechanical-draft cooling towers, the estimated installation costs were $72,000,000, with loss of capability and operating expenses estimated to be $45,000,000, totaling $117,000,000.

For natural-draft towers, the installation costs were estimated to be $79,000,000, with capability loss and operating costs amounting to an equivalent $45,000,000, totaling $124,000,000.

Installation charges on dry mechanical-draft cooling towers were estimated to be $343,000,000, with an additional $103,000,000 required for capability loss and operating expenses, yielding $446,000,000 for the present total worth. The addition of specially constructed spray ponds and even spray devices within the lake itself were considered along with a cooling lake as the remaining alternatives. No cost estimates were made for these.

The reader should be aware of the fact that the Zion cost estimates were based on specialized tower designs. Air traffic in the Zion vicinity requires limitations on the maximum tower height; 250 ft was used as a design basis.

5. Waukegan and State Line Plants

Cost estimated for backfitting the Waukegan and State Line Power Plants with subsurface high-velocity discharges were presented in a letter from O. D. Butler, Commonwealth Edison, to the Chairman of the Four-State Enforcement Conference.[20] The letter stated that the initial capital investment, including escalation, contingency, and top allowances for backfitting the Waukegan Station with mechanical- and natural-draft cooling towers, would be (as revised) $14,174,000 and $19,448,000, respectively. With the equivalent capital investment for operating expenses and loss in capacity included, the total cost of backfitting the Waukegan station with towers was given as $21,390,000 and $25,755,000, respectively.

For the State Line Plant, the total costs for backfitting with mechanical- and natural-draft towers were estimated to be (as corrected)

$37,128,000 and $51,195,000, respectively. The estimated capital investment alone for the State Line plant towers was given as $26,983,000 and $38,657,000, respectively.

6. Michigan City Plant

Mr. C. W. Kern, Northern Indiana Public Service Company, provided a capital-cost estimate of $14,227,491 for backfitting the 719-MWe Michigan City Generating Station with an evaporative-tower system.[63] This plant has four units; one 500-MWe unit is currently under construction. Much of the cooling-system facilities originally designed for this unit were still usable for the closed-cycle tower system, and this estimate reflects the situation. No other information concerning operating expenses or capacity makeup costs were given.

7. Bailly Nuclear Plant

In the Environmental Statement for the 685-MWe Bailly Plant,[120] two cooling schemes were discussed: a natural-draft evaporative tower (to be used at the facility) and an alternative once-through system. The capital-cost differential between the tower and the once-through system was given as $7,000,000. The operating-cost differential evaluated on a present-worth basis, assuming a 30-year plant life and discount rate of 8.75%, showed the tower to require an additional $4,000,000; the total evaluated cost differential thus was $11,000,000. The Bailly plant is currently under initial phases of construction. Hence these cost estimates are for a new facility with the cooling system optimized for both alternatives; i.e., these are not backfitting-cost differentials.

8. D. C. Cook Plant

Testimony by John Tillinghast, Indiana & Michigan Electric Company concerning backfitting the D. C. Cook Plant with evaporative-cooling towers was given at the Michigan hearings.[84] The capital cost for natural-draft towers was stated to be $55,935,000, including interest and escalation. (These figures update information given earlier on the D. C. Cook Plant.) In addition to this, $6,000,000 per year was estimated to account for operating and power-loss replacement costs. These costs were translated to the consumer by proposing that they could be divided equally among the 358,545 utility customers. With this so done, the bills of these customers were stated to increase on the average between 7.5 and 9%, or by about $41 per year.

The Environmental Report[65] for the Cook Plant added that the cost of backfitting the plant with mechanical-draft towers would be about $63,000,000. An annual penalty of about $3,400,000 would be incurred as the result of losses in plant efficiency. The cost of backfitting the plant with a cooling pond was said to be about $60,000,000. A significant loss in plant efficiency would result with pond operation. This loss, when translated into dollars, represented an additional operating cost of about $6,000,000 per year.

9. Palisades Plant

Cost estimates for backfitting the 700-MWe Palisades Power Plant with evaporative towers perhaps represents the best information currently available, since this plant is actually effecting a change from once-through to mechanical-draft cooling towers. In a letter from R. C. Youngdahl, Consumers Power Company, to L. R. Rogers, USAEC,[136] Mr. Youngdahl estimated the capital cost of backfitting with a mechanical-draft tower system as $20,000,000 and the increased annual operating cost as $4,500,000. In the Environmental Statement for the Palisades Plant,[119] the 4.5-million-dollar value was used to calculate an equivalent present-worth value of $47,000,000 based upon a 30-year plant life and a 8.75% yearly discount rate. The incremented cost of the mechanical-draft towers, backfitted over the presently installed once-through system, was then estimated to be $67,000,000 on a present-worth basis. Relative costs cited the report for backfitting with high-velocity onshore or offshore discharges ranged from 1 to 5 million dollars, respectively.

10. General Observations

John Z. Reynolds, Consumers Power Company, testified at the Michigan hearings[84] concerning the cost of outfitting Consumer's 750-MWe system, present and proposed, with towers. He estimated that $76,000,000 would be required in capital costs and $73,000,000 additional would be required to account for the 3-5% system-capacity losses. Total annual costs, including fixed charges, added fuel costs, and operating and maintenance costs were estimated to be about $31,000,000 per year. Total capital costs, including equivalent costs, were projected to be about $244,000,000.

Mr. Wayne Wingert, Detroit Edison Company, testified at the Michigan hearings[84] that it would require about $200,000,000 in capital cost to convert the Detroit Edison System to closed-cycle cooling. He stated that this investment, including operating costs, maintenance, etc., would result in a total annual cost of $43,000,000 or roughly an increase of 12% in production cost per kilowatt hour, which would mean slightly less than a 6% direct increase in the customer's bill.

VI. CHEMICAL INPUTS

A. Summary of Power-plant Effluents

Only limited information is available as to the chemical effluents discharged to Lake Michigan from the power plants around its shoreline. Significant data are available in the applications for permits to discharge, submitted to the Army Corps of Engineers. The operators of all power plants have been requested to file such applications within the past year. Of the 27 power plants discharging, or to discharge into Lake Michigan or near the mouth of its streams, 18 applications were available at the time they were reviewed in the Region V EPA Office.

Examining the information in the applications revealed a number of inconsistencies and a substantial lack of the information required. Chemical analyses of intake and effluent water were not available with precision adequate to allow the calculation of incremental loads by direct subtraction, except in unusual circumstances. The best information, and it is believed the most pertinent, was given in the applications for Plants No. 13, 14, and 16, the proposed Zion Nuclear Plant, and the operating Waukegan and State Line Plants. For these cases, chemical constituents actually added or expected to be added to the coolant streams were identified and numerical values given. Accordingly, the effluents of all other plants were prorated on the basis of the data for these three. (Due to variability in the composition of the effluent from the sluicing operation, the data in the application for the Waukegan Plant lacked internal consistency; for this reason, upon request, Commonwealth Edison provided average analyses for eight monthly samples,[21] and these data were used in the calculations.) This procedure uses the tacit assumption that water-treatment practices and procedures are the same for all the other plants as for those for which the data are available. This is not entirely true, and the magnitude of the inaccuracies cannot be evaluated at this time. Nevertheless, the results, summarized in Table 11, are probably approximately correct and of sufficient value to justify their publication.

Two separate categories were established, nuclear and coal-fired. In each category, the prorating was done in terms of the average power level at which the plants were operated, calculated, and shown for 18 of the plants in Table 5. The input information was the average megawatt-hours per day output of the plants, as provided by the power companies on the Corps of Engineers applications. These numbers were believed to be inaccurate in a few cases and were not available in several other cases. In these instances, an overall average operating megawatt level was assigned as follows: Using plant capacities from Federal Power Commission statistics,[49] average plant factors were calculated for the available 12 coal plants (52.7%) and two nuclear plants (64.0%). The coal-plant average was multiplied by the plant capacity to obtain the average megawatt levels for the remaining coal plants, and the nuclear-plant average

Table 11. Calculated Chemical Discharges into Lake Michigan in Pounds per Day

No.	Plant Name	MW_{AVG}	Total Solids	NH_3N	Kj-N	P_{tot}	P_{tot}**	SO_4	Cl	Na	Al	B	Ca	Cr	Fe	K	Mg	Zn
1	Escanaba	13.2*	160	0.1	0.2	0.1		94	18	17	1		18	0.00	0	2	0	0.02
2	Pullian	206.7*	2498	1.2	2.9	1.1	2.7	1473	275	267	14		276	.01	7	31	3	.30
3†	Kewaunee	337.6*	291	0	0	0.8		107	17	45	1	1.1	60	.00	0	2	19	.04
4†	Point Beach	659.8*	569	0	0	1.6		209	34	88	2	2.2	117	.00	0	4	38	.08
5	Manitowoc	36.3*	439	0.2	0.5	0.2		259	48	47	2		49	.00	1	5	1	.05
6	Edgewater	242.3*	2929	1.4	3.4	1.3	0.9	1726	322	313	16		324	.01	8	36	4	.35
7	Port Washington	258.2	3121	1.4	3.6	1.4	8.9	1840	344	334	17		345	.01	8	38	4	.38
8	Commerce	19.75	239	0.1	0.3	0.1	2.1	141	26	26	1		26	.00	1	3	0	.03
9	Wells	4.04	49	0.0	0.1	0.0		29	5	5	0		5	.00	0	1	0	.01
10	Valley	180.8	2185	1.0	2.5	1.0	6.3	129	241	234	12		242	.01	6	27	3	.26
11	Lakeside	100.2	1211	0.6	1.4	0.6	7.6	714	133	129	7		134	.00	3	15	2	.15
12	Oak Creek	979.5	11839	5.5	13.6	5.4	4.4	6979	1304	1265	64		1162	.04	31	145	16	1.43
13†	Zion	1208.4	1042	0	0	2.9		382	62	162	4	4.0	214	.01	0	7	69	.15
14	Waukegan	587.5	7101	3.3	8.2	3.2	5.1	4186	782	760	39		785	.03	19	87	10	.86
15	Winnetka	13.4*	162	0.1	0.2	0.1	0	95	18	17	1		18	.00	0	2	0	.02
16	State Line	584.6	7066	3.3	8.1	3.2	3.8	4165	778	755	38		782	.02	19	86	10	.85
17	Dean H. Mitchell	218.2*	2637	1.2	3.0	1.2	1.0	1555	290	282	14		292	.01	7	32	4	.32
18	Bailly (Coal)	324.2*	3919	1.8	4.5	1.8	0.4	2310	431	419	21		433	.01	10	48	5	.47
19†	Bailly (Nuclear)	422.8*	365	0	0	1.0		134	22	57	1	0.0	75	.00	0	2	24	.05
20	Michigan City	206.0	2490	1.2	2.9	1.1		1468	274	266	14		275	.01	7	30	3	.30
21†	Donald C. Cook	1408.9*	1215	0	0	3.4		445	72	189	4	4.7	250	.01	0	8	80	.17
22†	Palisades	538.1*	464	0	0	1.3		170	28	72	2	1.8	95	.00	0	3	31	.07
23	James de Young	25.5*	308	0.1	0.4	0.1		182	33	33	2		34	.00	1	4	0	.04
24	J. H. Campbell	494.7	5979	2.8	6.9	2.7		3525	658	639	32		661	.02	16	73	8	.72
25	B. C. Cobb	336.0	4061	1.9	4.7	1.8	0.6	2394	447	434	22		449	.01	11	50	5	.49
26	Bayside	16.7	202	0.1	0.2	0.1		119	22	22	1		22	.00	1	2	0	.02
27†	Big Rock	52.9	45	0	0	0.1		17	3	7	0	0.0	9	.00	0	0	3	.01
TOTAL		9476.3	62586	27.3	67.6	37.6		34847	6687	6884	332	13.8	7152	0.21	156	743	342	7.64

*Avg. power assigned from power rating and avg. plant factor for other nuclear or coal-burning plants.

**Calculated from PO_4 use given by company on Federal Power Commission Form 67 for 1969

†Nuclear

was multiplied by the capacities to obtain the average megawatt levels for the remaining nuclear plants. These values are given in the third column of Table 11.

There was an additional source of information for estimating the total phosphorus added to the lake. Several of the plants had filled Federal Power Commission Form 67 for the year 1969, showing the quantity of phosphate added to the boiler makeup water for the year. If essentially all this phosphate is discharged to the lake, then the numbers calculated from this source of information should be about the same as those obtained by prorating the experience at Zion, Waukegan, and State Line. The numbers in column 8 were derived in this fashion from those FPC Form 67's available in the Region V EPA Office. There is substantial deviation from the prorated numbers in perhaps one-third of the entries; these may be explainable in terms of variations in local practices.

Examination of the numbers in Table 11 shows that when all 27 plants are operating, about 63,000 lb/day of total solids can be expected to be added to Lake Michigan. This is some 11,400 tons/yr. Based on 173 x 10^{12} cu ft of water in Lake Michigan, this corresponds to 0.002-ppm/yr increase in solids content. The total nitrogen content of the discharges can be expected to be about 70 lb/day, and the total phosphorus content some 40 lb/day.

The numbers given for boron discharged are probably less accurate than the others. The discharge occurs for pressurized-water nuclear plants whenever there is a leak between the primary and secondary coolant circuits. For design purposes, the Commonwealth Edison Co. estimated that a small leak would occur for 2 weeks per year. These numbers were then prorated for the other pressurized-water nuclear plants. For the two boiling-water reactor plants, zero is entered. The quantity of the objectionable chromium is small, of the order of 0.25 lb/day. The aluminum and zinc are primarily added at coal-burning plants, where they are leached from the fly ash.

In spite of the uncertainty in the numbers reported in Table 11, it is shown that coal-fired plants discharge more chemicals into the lake per megawatt than do nuclear plants. In the table the ratio is greater than 14. The most important contributing factor to this is the sluicing of ashes and fly ash at the coal-burning plants and the discharge of the sluicing water to the lake.

B. Standards Applicable to Power Plants

The Environmental Protection Agency draft final report on steam-generating plants[9] identifies manufacturing processes systems, and waste loads under the following categories:

A

Table 11. Calculated Chemical Discharges into Lake Michigan

o.	Plant Name	MW_{AVG}	Total Solids	NH_3N	Kj-N	P_{tot}	P_{tot}**	SO_4	Cl	Na	Al
1	Escanaba	13.2*	160	0.1	0.2	0.1		94	18	17	1
2	Pulliam	206.7*	2498	1.2	2.9	1.1	2.7	1473	275	267	14
3†	Kewaunee	337.6*	291	0	0	0.8		107	17	45	1
4†	Point Beach	659.8*	569	0	0	1.6		209	34	88	2
5	Manitowoc	36.3*	439	0.2	0.5	0.2		259	48	47	2
6	Edgewater	242.3*	2929	1.4	3.4	1.3	0.9	1726	322	313	16
7	Port Washington	258.2	3121	1.4	3.6	1.4	8.9	1840	344	334	17
8	Commerce	19.75	239	0.1	0.3	0.1	2.1	141	26	26	1
9	Wells	4.04	49	0.0	0.1	0.0		29	5	5	0
10	Valley	180.8	2185	1.0	2.5	1.0	6.3	129	241	234	12
11	Lakeside	100.2	1211	0.6	1.4	0.6	7.6	714	133	129	7
12	Oak Creek	979.5	11839	5.5	13.6	5.4	4.4	6979	1304	1265	64
13†	Zion	1208.4	1042	0	0	2.9		382	62	162	4
14	Waukegan	587.5	7101	3.3	8.2	3.2	5.1	4186	782	760	39
15	Winnetka	13.4*	162	0.1	0.2	0.1	0	95	18	17	1
16	State Line	584.6	7066	3.3	8.1	3.2	3.8	4165	778	755	38
17	Dean H. Mitchell	218.2*	2637	1.2	3.0	1.2	1.0	1555	290	282	14
18	Bailly (Coal)	324.2*	3919	1.8	4.5	1.8	0.4	2310	431	419	21
19†	Bailly (Nuclear)	422.8*	365	0	0	1.0		134	22	57	1
20	Michigan City	206.0	2490	1.2	2.9	1.1		1468	274	266	14
21†	Donald C. Cook	1408.0*	1215	0	0	3.4		445	72	189	4
22†	Palisades	538.1*	464	0	0	1.3		170	28	72	2
23	James de Young	25.5*	308	0.1	0.4	0.1		182	33	33	2
24	J. H. Campbell	494.7	5979	2.8	6.9	2.7		3525	658	639	32
25	B. C. Cobb	336.0	4061	1.9	4.7	1.8	0.6	2394	447	434	22
26	Bayside	16.7	202	0.1	0.2	0.1		119	22	22	1
27†	Big Rock	52.9	45	0	0	0.1		17	3	7	0
TAL		9476.3	62586	27.3	67.6	37.6		34847	6687	6884	332

*Avg. power assigned from power rating and avg. plant factor for other nuclear or coal-burning plants.

**Calculated from PO_4 use given by company on Federal Power Commission Form 67 for 1969

†Nuclear

B

Chemical Discharges into Lake Michigan in Pounds per Day

tot**	SO_4	Cl	Na	Al	B	Ca	Cr	Fe	K	Mg	Zn
	94	18	17	1		18	0.00	0	2	0	0.02
2.7	1473	275	267	14		276	.01	7	31	3	.30
	107	17	45	1	1.1	60	.00	0	2	19	.04
	209	34	88	2	2.2	117	.00	0	4	38	.08
	259	48	47	2		49	.00	1	5	1	.05
0.9	1726	322	313	16		324	.01	8	36	4	.35
8.9	1840	344	334	17		345	.01	8	38	4	.38
2.1	141	26	26	1		26	.00	1	3	0	.03
	29	5	5	0		5	.00	0	1	0	.01
6.3	129	241	234	12		242	.01	6	27	3	.26
7.6	714	133	129	7		134	.00	3	15	2	.15
4.4	6979	1304	1265	64		1162	.04	31	145	16	1.43
	382	62	162	4	4.0	214	.01	0	7	69	.15
5.1	4186	782	760	39		785	.03	19	87	10	.86
0	95	18	17	1		18	.00	0	2	0	.02
3.8	4165	778	755	38		782	.02	19	86	10	.85
1.0	1555	290	282	14		292	.01	7	32	4	.32
0.4	2310	431	419	21		433	.01	10	48	5	.47
	134	22	57	1	0.0	75	.00	0	2	24	.05
	1468	274	266	14		275	.01	7	30	3	.30
	445	72	189	4	4.7	250	.01	0	8	80	.17
	170	28	72	2	1.8	95	.00	0	3	31	.07
	182	33	33	2		34	.00	1	4	0	.04
	3525	658	639	32		661	.02	16	73	8	.72
0.6	2394	447	434	22		449	.01	11	50	5	.49
	119	22	22	1		22	.00	1	2	0	.02
	17	3	7	0	0.0	9	.00	0	0	3	.01
	34847	6687	6884	332	13.8	7152	0.21	156	743	342	7.64

n

3.3 Standard Manufacturing Processes
        3.3.1.1 Chlorination
        3.3.1.2 Filtration
        3.3.1.3 Clarification
        3.3.1.4 Lime-Soda
        3.3.1.5 Ion Exchange Processes
        3.3.1.6 Evaporation
        3.3.1.7 Reverse Osmosis
    3.3.2 Boilers
    3.3.3 Condenser
    3.3.4 Condensate Treatment
    3.3.5 Ash Handling

3.4 Auxiliary Processes

    3.4.1 Condenser Cooling Water Heat Disposal Systems
        3.4.1.1 Once-through Condenser Cooling
        3.4.1.2 Cooling Device on Condenser Discharge with Recirculation
        3.4.1.3 Cooling Device on Condenser Discharge
        3.4.1.4 Cooling Device on Condenser Discharge with Partial Recirculation and/or Dilution
    3.4.2 Service Water Systems
    3.4.3 Sewage Plants
    3.4.4 Cool Storage
    3.4.5 Oil Leakage
    3.4.6 Hydrovactors
    3.4.7 Other On-site Activities
    3.4.8 Accidental Potential Pollution Sources

3.5 Typical Future Manufacturing Processes

3.6 Normal In-plant Pollution Control

4. Standard Raw Waste Loads

4.1 Concept of Standard Raw Waste Load

4.2 Waste Load Data Sources

4.3 Standard Raw Waste Loads from Standard Manufacturing Processes

    4.3.1 Water Treatment
    4.3.2 Boiler
    4.3.3 Condenser
    4.3.4 Condensate Treatment
    4.3.5 Ash Handling

4.4 Standard Raw Waste Loads from Auxiliary Processes

    4.4.1 Heat Disposal Systems
    4.4.2 Service Water Systems
    4.4.3 Other Waste Water Sources

Typical waste loads are tabulated, and some methods of reducing quantities of waste are outlined. The standards are intended to facilitate consideration of the effects of power plants on the environment.

C. Chemicals for Removal of Organic Deposits in Condensers and Process-Water Systems

When natural waters are passed through circuits of the kind used in power plants, fouling deposits that interfere with the flow of water and heat form on all surfaces with which the water comes in contact. These deposits may be in the form of hydrous oxides of metals, such as iron and chromium; they may be scales, such as carbonates or sulfates of calcium and magnesium; or they may be organic in nature. The organic deposits are formed by the deposition of living organisms, followed by their continued growth. In the presence of sunlight, the organic deposits are typically algal, whereas in unirradiated heat-transfer equipment, they are typically bacterial.

For removal of the slime formed in power-plant condensers and other heat exchangers (such as those in the process-water systems), chlorine, added to the cooling water, has been found to be effective and inexpensive. In most power plants, it is injected into the cooling water in the form of elemental chlorine or in the form of a strong solution of sodium hypochlorite for a few relatively brief (10 or 15 min typically) periods per day. This system is called shock defouling. A considerable fraction of the organisms in the deposits are killed, and the organic material and much of the scale are dislodged and carried out in the cooling water. Organic material formed on all parts of the system downstream of the condenser reacts with residual chlorine and helps to reduce its level at the point of discharge to the lake.

In addition to its toxicity to the slime bacteria, chlorine has the advantage that it is chemically unstable in water and is quickly degraded in nature. This reaction is catalyzed by light; the data of Hancil and Smith,[56] as treated by Draley,[40] show that under the laboratory ultraviolet illumination, the time in seconds to reduce the concentration of free chlorine from c_0 to c is $t = 7.8 \ln (c_0/c)$. This advantage is partially lost if ammonia is present in the cooling water, since the chloramines formed by reaction between ammonia and chlorine have longer lifetimes in natural waters than does the free chlorine (which exists in the form of hypochlorous acid or the hypochlorite ion).

The optimum utilization of chlorine for defouling would require that the chlorine and chloramines be decayed or dissipated before discharge of the effluent stream to the lake (or other natural bodies of water in more general terms). A common chlorination practice, though by no means universally practiced, which helps to achieve this condition, is to have the total circulating-water stream divided into parts, only one of which is chlorinated at a time. The remixing of the chlorinated and unchlorinated streams then leads to the removal of chlorine by the so-called chlorine-demand constituents of the untreated water. It is also possible to remove residual chlorine chemically by adding reducing agents such as sodium sulfite or bisulfite. For example, in one installation a ratio of sodium bisulfite to residual chlorine of 3.8:1 decreases the residual chlorine level from 1 to below 0.1 ppm in less than 5 sec.[89]

The use of chlorine and the problems pertinent to the avoidance of significant toxic doses to the lake (or other receiving waters) are the subjects of the recent analysis by Draley.[40] The need for (a) standards, (b) discharge monitoring, and (c) development of calculational knowledge and skills are emphasized.

Significant new publications related to chlorine and its toxicity concern standards and the effects of dilute solutions on fishes.

In the area of standards, the Michigan Water Resources Commission, Water Quality Control Division, issued in the spring of 1972 an Interim Effluent Standard for Industrial Discharges of Chlorine (to be reviewed as to adequacy and suitability on or before December 1972).[85] It specifies that "Waste streams shall contain not more than 0.05 mg/ℓ of total chlorine (free and combined) in the discharge to receiving waters after utilizing available dilution and at a point to be determined by the Chief Engineer of the Commission, where application of chlorine is on a continuous basis; or contain not more than 0.5 mg/ℓ of total chlorine (free and combined) in the discharge to receiving waters after utilizing available dilution and at a point to be determined by the Chief Engineer of the Commission, where continuous application of chlorine will be limited to not more than 30 minutes during any 2-hour period."

On December 20, 1971, William A. Brungs forwarded to Mr. Francis T. Mayo, Regional Administrator for EPA Region V, "Water Quality Criteria Recommendations for Residual Chlorine in Receiving Waters for the Protection of Fresh Water Aquatic Life," by the Staff of the National Water Quality Laboratory, Duluth, Minnesota.[45] Four separate levels of residual chlorine, that would be applicable to Lake Michigan or other receiving water, were identified, in terms of toxicity and usage. During continuous use at 0.01 mg/liter or less, trout reproduction and some important fish food organisms would probably not be protected and the situation could be partially lethal to sensitive life stages of sensitive fish species. For continuous usage at 0.002 mg/liter most aquatic organisms should be protected. For intermittent use at 0.1 mg/liter, not to exceed 30 min/day; or 0.05 mg/liter, not to exceed 2 hr/day, significant kills of aquatic organisms should not occur and the aquatic ecology should not be adversely affected. These recommendations require the use of the amperometric titration method; some of the other methods commonly used in the determination of residual chlorine have been shown to be inaccurate. The National Water Quality Laboratory recommendations were reissued about June 1972.[46] There were no changes in the specific recommendations. The text was modified, apparently with the objective of assisting the reader in considering possible applicability of the criteria.

The same document summarizes the literature that is most pertinent to quantitative effects of low levels of residual chlorine on a number of varieties of fish species. Twenty-four references are given. Dr. Brungs has prepared a more extensive literature review on the effects of residual chlorine on aquatic life.[18] Covered are the aqueous dilute solution chemistry of chlorine, its effects on aquatic life, chlorinated wastewater treatment plant effluent, chlorination for antifouling, and results of standard bioassays. The following general statements resulted from the review: (1) Tests of residual chlorine toxicity should be conducted using continuous-flow bioassay procedures and the most precise, sensitive, and appropriate analytical method for determining residual chlorine; (2) typical environmental variables do not significantly affect residual chlorine toxicity, although at lower pH toxicity may be increased as a result of the greater proportion of free chlorine present, but this difference is slight; (3) trout, salmon, and some fish-food organisms are more sensitive than warm-water fish, snails, and crayfish; (4) chronic toxicity effects on growth and reproduction occur at much lower concentrations than acutely lethal concentrations; (5) most of the lethal effects of residual chlorine occur within 12-24 hr, with lethal effects of free chlorine being more rapid than those of chloramines; (6) chlorination of wastewater results in a variety of chlorinated compounds in addition to chloramines, and this aspect needs much greater research emphasis; (7) residual chlorine is more persistent than the few minutes or hours indicated by some authorities; (8) dechlorination with sodium bisulfite, sodium thiosulfate, and sulfur dioxide, among others, greatly reduces or eliminates toxicity due to residual chlorine, and the potential chronic toxicity resulting from such additional treatment requires further research; (9) substitutes for chlorination of wastewaters or cooling waters should be used whenever feasible, but only after adequate acute and chronic toxicity studies to determine the potential environmental impact of the substitutes, and their efficacy as adequate disinfectants must be verified.

The Staff of the Michigan Water Resources Commission has under way a program to assess, under field conditions, the effects of chlorinated condenser cooling water on aquatic life. Truchan and Basch[118] have reported observation of a major fish kill and concomitant analyses for total residual chlorine near the Karn-Weadock power plant complex near the mouth of the Saginaw River. A maximum 1.36 mg/liter of residual chlorine was detected during the period of measurement (corresponding to the time of addition of chlorine in the plant). This study shows that intermittent discharges of chlorine from power plants can be acutely toxic to fish life in the discharge channel, perhaps partly because fish sometimes congregate in the vicinity of plant-water discharges. Caged fish studies at the same plant were reported by Basch and Truchan[11] and Wuerthele and Truchan.[135]

Short-term tests at chlorine levels up to 0.4 mg/liter were run. Fathead minnows suffered no mortality during the exposure periods. Rainbow trout, however, suffered 90% mortality after exposure to an average total residual chlorine (TRC) concentration of 0.106 mg/liter for 16.18 hr out of the 62-hr test period. Mortality was also observed after the second exposure for 5.52 hr out of the 29-hr test period. Acknowledging the fact that the fish in the study were caged and could not avoid the discharge, the results do indicate that intermittent low-level discharges of chlorine from power plants can be toxic to certain fish species resident in the discharge area.

Massey, also of the Bureau of Water Management, described the avoidance of chlorine discharges and the killing of fish at the Big Rock Point power plant in May 1972.[81] The TRC level in the discharge channel rose, briefly out of control due to a malfunction, to a maximum measured value of 3.05 mg/liter. The highest readings obtained in the plant by Consumers Power personnel using the orthotolidine color comparator was 0.2 mg/liter TRC. Instances of apparent incorrectly low readings through the use of the orthotolidine comparator have also been recorded at other sites.

Fish kills due to chlorine discharge in power-plant circulating water have also occurred in other water bodies, including salt water. Fairbanks, Collings and Sides[48] have reported such events in the Cape Cod Canal.

The Michigan Bureau of Water Management has also done caged-fish field research downstream of municipal wastewater-treatment plants. In one study, sponsored by EPA, toxicity to rainbow trout has been shown at distances up to 0.8 mile downstream. Fathead minnows appeared adversely affected up to 0.6 mile downstream. Total residual chlorine concentrations less than 0.1 mg/liter were toxic to fathead minnows. The rainbow trout 96-hr total residual chlorine PL-50 concentration below two plants was 0.023 mg/liter.[86]

Alternatives to chlorine defouling, receiving increasing attention, are mechanical methods of removing fouling deposits. Mechanical devices can consist of balls, plugs, or brushes; they are blown through the tubes of heat exchangers such as steam condensers by the force of the flowing fluid or by mechanical devices. Automatic systems are offered by Amertap Corporation and American M. A. N. Corporation. The Amertap system circulates sponge-rubber balls in a special bypass cooling-water stream. The M. A. N. System uses nonmetallic brushes, which are restrained in the tubes by plastic baskets attached to the ends of each tube. By reversing the flow of the cooling water, the operator can automatically "shoot" the tubes with the brushes. The Amertap system has received most favorable attention by American power companies; it is being installed in Commonwealth Edison's Zion Nuclear plant.

American experience with the Amertap system is limited, and it is not yet possible to say whether it will provide a desirable substitute for chlorine defouling in all situations. In particular, the entrainment of small debris sometimes leads to plugging when the debris and the ball enter a tube at the same time and restricts flow when it is entrapped in the ball-collecting device. Mechanical treatment is not ordinarily used in other places in power plants where defouling is required. Of particular note are the service-water systems used to remove heat from a number of auxiliary items of equipment at a typical plant. The installation of mechanical systems for each of these heat exchangers has been unattractive, and plants using mechanical treatment for condenser tubes still chlorinate service-water systems. In these cases it remains necessary to examine the concentration of residual chlorine after dilution with the main circulating-water stream. At Zion the resulting solution is more dilute than the maximum appropriate concentration in the EPA-recommended criteria.[46]

D. Chemicals for Treatment of Water-Steam System

Steam-boiler systems are typically treated with chemicals to minimize the formation of scale and corrosion products on steam-generator surfaces and to minimize corrosion in the remainder of the system. Makeup water is characteristically highly purified to minimize the amount of scale-forming chemicals, such as dissolved calcium and magnesium. Reducing agents such as hydrazine and sulphite are commonly added to maintain very low oxygen contents (oxygen accelerates corrosion of the steel system). Phosphate is added to help tie up the small residual amounts of calcium and magnesium and to serve as a corrosion inhibitor. Morpholine is added as a volatile corrosion inhibitor that will distil with the steam and protect return piping. Chromate has been used in some systems because of its effectiveness as a corrosion inhibitor. Since the last Enforcement Conference, no new information considered valuable to the Lake Michigan problem has been encountered.

E. Chemicals for Treatment of Cooling Towers and Ponds

The use of cooling towers simplifies the treatment of waste heat, but adds complexity in water treatment. Cooling-tower recirculating systems, and in particular the towers themselves, have corrosion and fouling problems that are more difficult to treat adequately than once-through cooling systems. Bacterial and algal slimes sometimes grow rapidly on the aerated cooling-tower circuits. Some companies are now trying to develop new and optimized chemical treatments. Although there has been no universally used chemical treatment of recirculating circuits, and hence no standard content of additives in the blowdown, a group of chemical additives is commonly encountered. Mixtures of chromate, zinc, and phosphate are commonly used for corrosion control. Microbial problems are controlled by addition of chlorine, hypochlorites, and nonoxidizing organics, such as chlorophenols, quaternary amines, and organometallics. Silt deposition is controlled by use of polymers such as lignin-tannin dispersives, polyacrylamide, polyacrylates, polyethyleneimine, and other polyelectrolytes. Acid or alkali is used for pH control, and organic phosphorus compounds such as organic phosphates, aminomethylene phosphonate, and polyesters are often used to control corrosion and scale formation and to provide dispersing effects.[54]

The Atomic Energy Commission, in its environmental statement for the Palisades Plant,[119] has warned of the possibility that cooling towers might prove, overall, more adverse to the environment than once-through cooling and discharge to Lake Michigan. The following is quoted from the Summary and Conclusions section of that document:

"The use of the (cooling) towers reduces impingement, entrainment and thermal impact on fish and other aquatic biota. However, they introduce a long-term adverse impact of chemicals from continuous blowdown ... of concentrated salts which would accumulate in Lake Michigan over the long-term operation of the cooling towers and cause serious degradation of the water quality of Lake Michigan in the vicinity of the Plant. The increased concentration would result in phosphate enrichment of the lake water and reconcentration of zinc and chromate in biota.

"Cooling towers introduce terrestrial environmental impacts on flora and fauna ... from chemicals deposited by the drift, evaporation ... of lake water, fogging under certain meteorological conditions, and icing in the winter. Although the (Palisades) towers are hidden from view, they will cause an adverse aesthetic effect from the lake side and will have a noise impact on the area.

"(For Palisades) the cooling towers will not only require an increase in capital and operating costs of the order of about $67,000,000 but will result in a decrease of about 3% in net electrical output due to the electrical power required for the fans in the towers."

These statements are supported by an appended 18-page review and evaluation of "Cooling Tower Chemicals--Potential Environmental Degradation." Also included is a discussion of blowdown treatment to remove the toxic elements chromium and zinc. Commercially available methods for these removals could be applied to recirculating cooling water system blowdown.

There are some notable differences between the treatment of recirculating cooling-tower circuits with chlorine and the treatment of once-through circulating-water circuits with chlorine. Since the chlorine in the recirculating circuit must not only clean the condenser tubes, but also the surfaces in the cooling tower, it is no longer possible to add chlorine only to the extent necessary to last for passage through the condensers. Instead it is necessary to overcome the total chlorine demand in the entire recirculating system, both in the form of dissolved chemicals and organic deposits on surfaces. Chloramines, produced by the reaction of free chlorine with nitrogen-bearing compounds, are lost to a considerable extent by volatilization in the aeration while passing through the cooling tower.[55] It is also possible to chlorinate by adding enough free chlorine to initiate the "breakpoint" reaction, in which the chloramines are oxidized to nitrous oxide, which is in turn lost by aeration. The techniques and the operating procedures for cooling-tower circuits have not yet been well established, and remain to be optimized. Additionally it will be necessary to establish some procedure in which the residual chlorine in the recirculating cooling water is not discharged to the natural body of water through the blowdown during periods of chlorination. Possibly blowdown could be suspended for periods; plants now being built have included holding ponds in the blowdown circuit so there is time for chlorine decay before discharge. Separately pumped dilution streams are possible, and chemicals could be added to remove the residual chlorine. No cooling-tower recirculating cooling circuits are operating on Lake Michigan. The Palisades Nuclear Plant, the Bailly Nuclear Plant, and the Michigan City Plant are planning to operate in this fashion.

No cooling ponds are proposed for use on the shores of Lake Michigan. For other installations, such cooling ponds have effected certain simplifications. Short-term chemical additions are discharged, in a more dilute form, over a longer period of time. Unstable chemicals like chlorine are typically completely decayed away before reaching the point of blowdown, and so are not significantly present in the plant discharge.

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